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Geneva 1958

THE Second International Conference on the Peaceful Uses of Atomic Energy has come to an end; and engineers and scientists, executives and salesmen have returned to their own establishments, to make up for the time lost as a result of the mass exodus of staff and the months of preparatory work.

The standard excuse for a large international conference is that it benefits international relations, and by providing an opportunity for frank discussions speeds the development of a particular technology, cuts out waste, avoids duplication and stimulates developments. Whether these vast gatherings do improve international relations is a matter of opinion. Frequently such gatherings are used for political ends and prosaic technical information is used as a vehicle to gain political advantage. On the whole, however, the atmosphere at Geneva was cordial and political overtones were not pronounced.

The amassing of technical representatives of many nations does give the opportunity for informal exchanges of views and for the middle grades to meet and to hear philosophies which are alien to their own laboratories.

Another justification put forward is that people are forced to put down their thoughts on paper. But papers should be written because there is something to say, not because policy demands one. Many of those submitted to Geneva should not have been written at all, others should have been considerably curtailed in length, others should have been published in different media (either in book or journal form). Clarity and brevity should have been the objectives instead of prestige. The summaries that accompanied the papers were, for the most part, quite useless and even the oral presentations at the sessions in many instances contained so much introduction and so many generalities that the technical value of the papers that they represented was lost. With few exceptions the discussion periods yielded little of value.

Fusion Declassified

Certainly at Geneva, the subject of thermo-nuclear fusion became firmly declassified and free discussion ensued on the many devices that are being used in experiments in Russia, the U.S. and the U.K. Are we quite sure, however, that if the second Geneva conference had not been planned three years ago, this declassification might not have occurred earlier? Fusion can be openly discussed because its widespread application is now recognized to be a long way off. But diffusion plant techniques, which have both a commercial and a military value, remained on the secret list in spite of French efforts to initiate an international declassification policy.

It would be easy to criticize the organizers of the conference for the unsatisfactory nature of many of the arrangements at Geneva. They were, however, attempting a near impossible task. A serious handicap, and one perhaps with deeper implications, concerned the inadequacy of the oral translations, particularly from the Russian. Simultaneous translation of highly technical subjects is, obviously, a formidable task, but there could have been more preparation. Some of the Russian papers became quite meaningless when heard as a mixture of rapid staccato sentences interspersed with long pauses.

The Exhibition

In many ways the exhibitions were the most rewarding aspect, with the Americans dominating the scientific exhibition, particularly with their thermo-nuclear display, and the British the commercial exhibition. It was unfortunate that these should be on opposite sides of the town and, inevitably, this forced a synthetic division between the commercial and scientific when, at least in the fission field. this division is no longer admissible.

At the Palais des Nations, the U.S. display of operating thermo-nuclear experiments was not only impressive but highly informative. In addition to the sheer interest of the machines themselves working in front of one (and built with a quality of design that was quite admirable), the stands were also manned by experts who were able to discuss their functions in detail. In the same building the Russian exhibition was disappointing, it was not until halfway through the conference that booklets were available in English. The display was inadequately manned by trained people, and even the placards had the minimum of translated captions. Throughout the conference the Russians have given the impression of slackening interest in the fission field, and less intense development in the thermo-nuclear field than many expected. Although they now have operating the largest single power reactor—the 100 MW unit in Siberia—steam temperatures of less than 400°F are hardly ambitious. The justification for some of the smaller nations exhibiting in the pavilion seemed small, their displays had little to say and their presence did little to enhance their prestige.

At the Palais des Expositions where the stands of the British companies received (and deserved) the highest praise, it could be seen that only the United Kingdom was at the present time seriously " in business " in the nuclear fission power field. The amount of selling concluded by the larger firms was small, but this was to be expected and the real effect of the Exhibition cannot be assessed for many months. Many of the smaller companies, however, were surprised at the weight of interest shown and were able to get to grips with markets that, in some cases, they had not appreciated really existed. There is little doubt that the United Kingdom showing has enhanced the prestige of this country's industrial effort and has demonstrated unequivocally the immediate availability of practical designs and components.

Power Programmes

In the fission field the tone of the conference was struck right from the beginning when, almost alone, the United

Kingdom reaffirmed its faith in nuclear energy as an immediate energy source while so many countries in effect were retracting or discussing programme schedules which implied a somewhat superficial interest at the present time. This is not to say that there are no markets abroad for power reactors, but the enthusiastic markets are limited. In Germany, for instance, it would appear that, although the academic interest is considerable, finance is not available.

One could not help being struck also by the determination of many countries to base their building programme solely on indigenous supplies of fuel. India, for example, in spite of having to import so much equipment in order to speed her industrial development, does not appear to be prepared to import uranium, even though a free market exists and there are many sources of supply. This nationalistic attitude towards nuclear power programmes, although so illogical, appears undiminished in spite of so much talk of international collaboration. Uranium is practically a drug on the market and reserves are ample for many years, but few countries seem to regard it as a normal commercial marketable product.

Reactors

In the reactor field great interest was expressed in the boiling water system. The U.S. has great faith in this reactor and their enthusiasm for the system undoubtedly made an impression. It is equally clear, however, that the economics of reactors other than the Calder type are still unknown and, although many figures were quoted, calculations are still somewhat arbitrary. Only by commercial building and operation can this question be resolved and, although so many aspects of the BWR are attractive, it has yet to be proved that the inevitable poor steam conditions do not introduce prohibitively low efficiencies. The BWR almost certainly has a future, but whether this is in large-scale electricity generation has yet to be proven.

With the greater operational experience available, the limitations of the present Calder system came in for much discussion, but there is still every reason to believe that the system is the best available for base load generation in this country, and many countries abroad, and also that the basic type is quite capable of development into peak load reactors. Although we have (as so many people are anxious to point out) no reason to be complacent about the gas-cooled reactor, we have equally no cause to be dissatisfied or feel disillusioned. At the same time there is no reason why we should have adopted such an unspectacular approach to the paper on the Calder successors. The complete demotion of the consortia's papers to the " also-rans " in the power sessions was most unfortunate, and gave a wrong impression. Our inability to produce direct evidence of 3,000 MWd/t burn-up was also regrettable although assurances on this point carried conviction.

World-wide interest is increasing in the heavy water moderated reactor and the experiments in Sweden and Canada are being followed with lively interest. In this country the gas-cooled heavy water moderated reactor is likely to receive intense development and this type might provide the solution to the problem of the small reactor.

We suspect, however, that some enrichment will be necessary in small reactors and this problem does not appear to be tackled seriously in the United Kingdom. From a long-term point of view plutonium may provide the answer, but the technology of using this material, although it has advanced since 1955, is by no means complete. There is the important in-between period when the availability and price of enriched uranium is of considerable significance in industrial development.

Ships

Although a number of papers at the conference discussed tentative designs for nuclear-propelled ships, it became quite clear that no system exists which can give the promise of competitive nuclear propulsion. Fuel costs can be brought down to the level and perhaps below the level of oil, but capital expenditure on the plant is inevitably high and, until systems can be developed with greatly reduced capital cost, commercial exploitation of nuclear energy for ship propulsion is not a practical proposition, except in certain very specialized cases as, for example, the " Lenin," where independence of shore-based depots is a facility that is worth a lot of money.

Fusion

Undoubtedly fusion was the star subject of the conference and for many provided the first insight into the magnitude of the problems and also demonstrated the very broad front along which these problems are being tackled, particularly in the United States and to a lesser extent in the U.S.S.R. Senior delegates from many countries were continually pressed on the question—when would thermonuclear fusion become a practical proposition. In general the 1955 forecast of Bhabha that it would take 20 years for the production of a machine with an energy gain was upheld, but time and again it was emphasized that an energy gain was only the beginning of commercial exploitation and it could easily be the turn of the century before economic fusion generation was possible.

In the face of the U.S. effort, the British work on ZETA and Sceptre might appear insignificant. Caught up in a wave of emotion at the beginning of the year, many people ascribed to ZETA characteristics which the scientists did not claim and potentialities which Harwell did not boast. When the situation was clarified at Geneva, and the problems of the pinch machine were fully discussed, there was a strong temptation to denigrate the U.K. effort. This attitude is wholly unjustified. ZETA is a possible road to producing a thermo-nuclear reaction and is a valuable tool for investigating the new subjects of plasma physics and magneto-hydrodynamics. Certainly, the d.c. machines of Oak Ridge and Russia captured the imagination and the forecast that these would produce a self-sustaining reaction in two years' time was exciting, but this self-sustaining in a d.c. machine should not be confused with an energy gain. It is quite possible that the right system has not yet been discovered and that many more devices will have to be built before even its basic principles can be understood.

One of the more surprising aspects of the conference concerned the papers on the measurement of nuclear constants. These constants and the calculations which support them are vital to the accurate assessment of the behaviour of reactor cores, particularly light water moderated cores where the neutron slowing down length is small. Although divergencies are less than in 1955, significant differences between measurements made by different methods still exist and the conference did little to throw light on where the discrepancies arise. Clearly much careful experimental work is needed before our knowledge of these constants can be considered either accurate or complete.

This Second International Conference on the Peaceful Uses of Atomic Energy was no doubt inevitable. It has not been valueless, and a careful evaluation of the material presented over a long period of time will no doubt give considerable enlightenment on many topics. But, equally clearly, this conference was too big and there should not be a third based on the same all-embracing principles.

DIGEST...

Surveying Significant News

N.P.P.C. Italian Contract Signed

On the eve of the opening of the Geneva Conference a formal contract was signed between SIMEA (the subsidiary of Agip Nucleare, which took over the original Agip gas-cooled graphite moderated power reactor project) and the Nuclear Power Plant Co. for the construction of a 200 MW nuclear power station to be built near Latina. The original agreement between N.P.P.C. and Agip was signed in May and this contract is the logical development. Value to British industry is in excess of £10 million and will include the supply of the reactor complete with turbo-alternators, blower units and other associated equipment. A similar expenditure in Italy will provide for the civil works, conventional machinery and erection of plant. The U.K.A.E.A. have guaranteed fuel for the life of the station. Work on this project in the U.K. has already begun and the station will be commissioned by mid-1962.

European Fuel Element Consortium

In Belgium two companies, Fabrique Nationale d'Armes de Guerre and the Société Générale Métallurgique de Hoboken, have formed a company called Métallurgie et Mécanique Nucléaires, the purpose of which is to design and fabricate components of nuclear reactors and especially all types of nuclear fuel elements, their assemblies as well as complete cores. The site for the company, which has been established with a capital of 100 million francs, has been chosen opposite the Centre d'Etude de l'Energie Nucléaire at Mol, and close to the site of the first nuclear power plant and the Eurochemic fuel processing plant.

U.S. Heavy Water Plans

To minimize capital requirements on heavy water reactors, the U.S.A.E.C. has announced that it is prepared to lease as an alternative to selling heavy water for use in both domestic and foreign research medical or testing reactors. Users now have the option of leasing the material at 4%/an. of the sales price or purchasing heavy water at the present established price of $28 per lb. Quantities of 1 short ton or more will be acceptable on this basis. For foreign research, medical or testing reactors, an agreement could be made for the estimated useful life of the reactor; for domestic testing reactors, the lease would be for a period of five years, subject to renewal.

The U.S.A.E.C. has invited proposals for performance studies on a heavy water-moderated power reactor capable of operating on natural uranium fuel. The Commission emphasizes that the invitation and the continuation of development work already initiated in 1956 do not imply necessarily that such a plant will be constructed. At the same time, the Du Pont Company will undertake the development, design and construction of a heavy water components test reactor to be located at the Savannah River Plant site.

British Thermo-Nuclear Research to move to Winfrith Heath

The U.K.A.E.A. has announced that the British thermo-nuclear project will be moved to Winfrith Heath, during the period 1961-1963. Work will continue on the machines already installed at Harwell and ZETA will be progressively modified to increase the discharge current and the containment times in the light of experiments currently in hand. Designs for ZETA II are not finalized but it is likely that, should a larger version of the present ZETA be built, this will be installed at Winfrith Heath. It is anticipated that by the time the move is complete about 1,000 people will be working on the fusion project, of whom 200 will be qualified technical staff.

Euratom Report Published

The first report of Euratom was published on September 21, although at the time of writing copies were not available in the U.K. This report, which reviews the first nine months of the Association's existence, will be debated by the six-nation parliament in its session beginning October 21. It is not clear yet whether Euratom will emerge as an effective force in co-ordinating European nuclear energy developments, but the report indicates that significant groundwork has been completed already.

U.S.S.R.-Czechoslovak Agreement

A bilateral agreement has been signed between the U.S.S.R. and Czechoslovakia concerning assistance in nuclear research and in the exploitation of atomic energy. The agreement provides for the delivery of an experimental reactor and cyclotron to Czechoslovakia and for the training of specialists. Czechoslovakia is aiming to construct a gas-cooled heavy water moderated reactor designed by its own engineers but using Russian fuel elements.

MTR Operates with Plutonium Core

The Materials Testing Reactor at the National Reactor Testing Station in the U.S. is now operating at a power level of 5 MW with a plutonium core and is expected shortly to reach its design power level of 30 MW. Diverging originally in 1952, MTR has been operating with U^{235} as fuel; only minor changes in design were required for the installation of the plutonium fuel elements. After a test period of operation it is proposed to reload with fuel elements fabricated from U^{233}. MTR has already been operated with U^{235} elements enriched 20%, whereas the original core used fully enriched uranium.

Experiments with CERN 600 MeV Synchro-cyclotron

Scientists working at CERN were able to announce during the Geneva conference the conclusion of the first piece of major research performed at the establishment. The experiment in question was concerned with the decay of the pi-meson, and was performed to check the theoretical prediction that approximately once every 10,000 times the meson should decay directly into an electron. This mode of decay had previously not been observed.

U.S. and U.S.S.R. Gifts to U.N.

During the Conference, both the U.S. and the U.S.S.R. presented to the United Nations documentation on their own experiments. The U.S.S.R.'s gift consisted of four volumes summarizing the thermo-nuclear research conducted in the Soviet Union from 1951 and the U.S. presented to the U.N. and to each of the participating nations a 13-volume set of books on the peaceful uses of atomic energy. These books contain hitherto unavailable or widely scattered information and have been prepared by leading U.S. scientists and engineers.

Calder Turbine Failure Report

The Board of Inquiry set up by the U.K.A.E.A. to inquire into the circumstances of an accident which damaged a turbo-generator in B power house at Calder Hall on June 28 has been published. It was established that overspeeding was caused by the coincident failure of two steam valves, traced to fragments of chilled iron shot which had found their way into the steam system.

Nuclear Marine Insurance Under Discussion

A conference of the International Union of Marine Insurance was held in Salzburg from September 1-5, at which views were exchanged on the risks that could be covered by insurance companies when nuclear-propelled merchant ships become operational. In general the British view is that comprehensive cover can be given whereas the Continental attitude is more cautious. The first nuclear surface ship in the Western world—the "Savannah"—is likely to have special Federal provision.

U.S.S.R Operate Largest Power Reactor

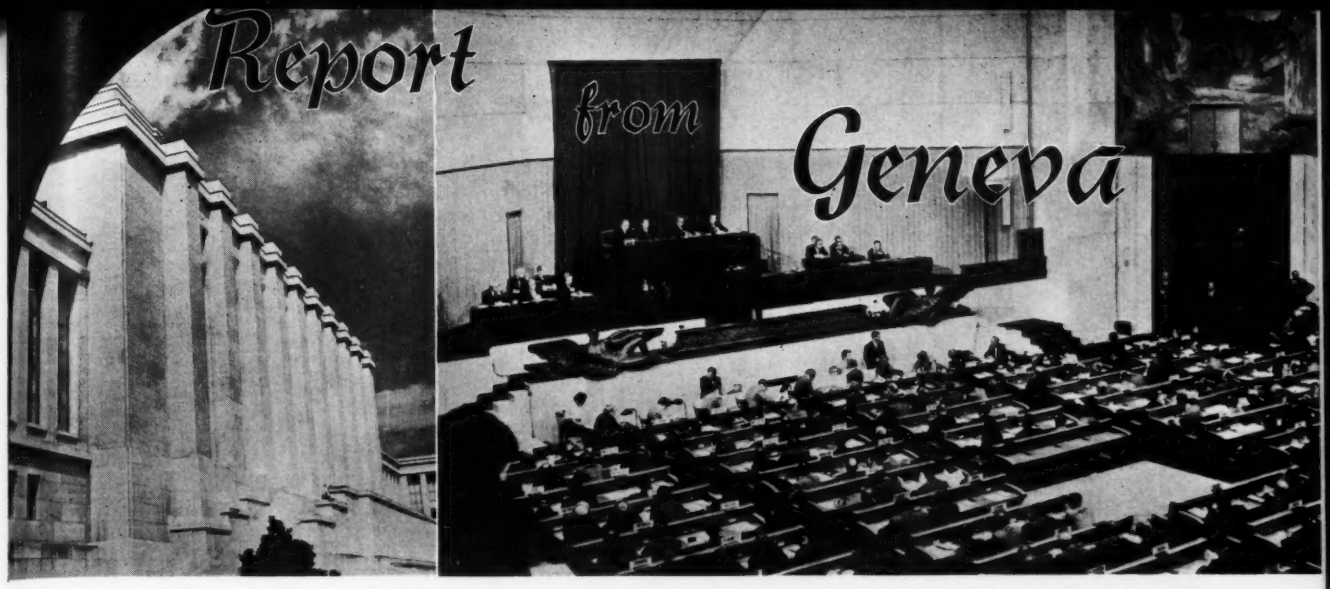
The first 100 MW(E) section of a 600 MW(E) power station using natural-uranium graphite-moderated water-cooled reactors went critical at the beginning of September somewhere in Siberia. The reactor is an advanced version of the first Russian power plant, fuel element size being increased to 6 m; aluminium alloy is still used as cladding, maximum primary outlet temperature of coolant 220° C, and steam temperature 180° C; total fuel charge in reactor 200 tons uranium. Fuel element replacement can be worked completely automatically, manually operated reserve machine also provided. Graphite stack liberally provided with moisture detectors in case of channel leakage.

Commonwealth Scientists Meet

Following Geneva, scientists from the Commonwealth countries came to Britain for a conference which opened at Harwell on September 15. The conference aims at increasing the co-operation between the Commonwealth countries. Discussion covered a wide range of subjects.

Reactor News in Brief

100 MW(E) water-cooled graphite-moderated reactor in Siberia, critical September 1. . . . HRE-2 now operating at design power of 5 MW. . . . "Triton" land-based prototype reactor critical August 18. . . . EBWR is to be up-rated to 100 MW instead of the present 29 MW at a cost of $\$1\frac{1}{2}$M. . . . CP5 with a rating of 2 MW is to be raised to 10 MW, at an estimated cost of $500,000.



1—National Power Programmes

Canada (183)

Present philosophy in Canada with its vast natural resources of conventional fuels, calls for nuclear power to be commercially competitive to warrant exploitation. This was not a forlorn hope, even in a country where the average cost is less than 6 mill/kWh. It is believed that a 200 MW station can be built to compete with a coal-fired station where fuel cost is $9/ton by the use of heavy water as a moderator and without fuel cycling.

Experiments with UO_2 elements indicated that from the metallurgical point of view burn-ups greater than 10,000 MWd/t were easily possible and Zircaloy-clad UO_2 elements should not introduce a fuel cost greater than 1 mill/kWh. 200 MW was at present regarded as a maximum electrical rating for the design but greater experience would, no doubt, increase this to 1,000 MW.

Only limited improvements in station capital costs are possible and higher temperatures leading to higher efficiencies are clearly necessary. A possible road to this is by using organics as coolants but Canada is predicated on the use of D_2O as moderator, the present price of which ($62 per kg) will probably fall.

A possible domestic programme envisages an installed nuclear capacity by 1966 of 200-1,000 MW, 600-1,700 MW by 1971, 2,000-3,300 MW by 1976 and 4,000-7,000 MW by 1981. This last figure calls for a natural U inventory of 3,150 tonnes, an annual U make-up of 1,050 tonnes and a heavy water inventory of 5,950 tonnes.

France (1131)

French fuel imports at present total 40% of consumption (as compared with 10% in the United Kingdom) but considerable effort is being expended on the harnessing of the tides and the development of the Lacq natural gas resources. The inevitable eventual exploitation of nuclear energy allows a more rapid burn-up of natural gas than could otherwise be tolerated and therefore tends to reduce the necessity of immediate installation of nuclear power stations.

At present G1 and G2 are operating and G3 will follow shortly; these last two reactors generate 30 MW(E) each. EDF1, which should become operational in early 1960 is rated at 63 MW (net E) and EDF2 which will follow 18 months later will be rated at 120 MW. It is anticipated that nuclear stations will then be built at the rate of one every 18 months, succeeding plant progressively increasing in size.

Total building requirements in France approximate 1,000 MW/an. but the present basic philosophy is aimed at gaining experience rather than establishing a set nuclear programme.

C.E.A. will build in addition to the gas-cooled graphite-moderated reactors CO_2-cooled D_2O-moderated reactors as a power prototype successor to EL2 and will probably be associated with Euratom in the construction of two American water reactors.

Russia (2027)

Russia has tremendous resources of conventional power but there are areas without local resources which must support large industries. The present programme includes a 420 MW (E) station under construction in the Voronezh region with two PWRs operating at 100 at and delivering saturated steam at 29 at via heat exchangers. The station is expected to generate in 1961 at a cost of 7-10 kopec/kWh as against 5-12 k/kWh for conventional stations. Fuel is 1.5% uranium-235 in Zircaloy cladding. A second station is to be built in the Leningrad region and it is anticipated that later types will dispense with the heat exchangers. To this end under construction in the Uljanovsk district is a 50 MW reactor employing similar fuel elements.

A station with four H_2O-cooled graphite moderated reactors giving a total output of 400 MW (E) is under construction at Beloyarsk in the Ural Mountains. The reactors are a development of the first power plant (*Nuclear Engineering*, Nov., 1956), and the turbines will run on live steam at 90 at and 480-490°C. Fuel elements are similar to the first station but are 6 m long as against 1.7 m.

The first 100 MW section of a 600 MW station in Siberia went critical on September 1. Designed to raise steam at a maximum temperature of 220°C and using aluminium fuel cladding the reactor is again water-cooled, graphite-moderated.

A boiling heavy-water HAR is to be built on the Volga, pressurized up to 50 at and rated at 35 MW to give information on boiling reactor stability and the thorium cycle efficiency. In addition, a 50 MW sodium-cooled graphite-moderated reactor is also to be built on the Volga.

A fast zero energy reactor was commissioned in April, 1955, followed in February, 1956, by a mercury-cooled reactor with a plutonium core. A 5 MW fast reactor using

Sir John Cockcroft and Prof. Emelyanov chatting before the opening of the Conference.

sodium as coolant designed with an exit temperature of 500°C and a plutonium core will be filled in a few months and run up to power. Two commercial variations are being designed, one of 50 MW for the Volga area and the other of 250 MW (E) for a place not yet decided.

Liquid-metal cores and organic moderation are also being investigated. A 50 MW intermediate test reactor with a flux of 2×10^{15} n/cm², sec is in preparation and a mobile plant rated at 2 MW (E) using a 120 atmos PWR for the opening up of new sites is scheduled for completion at the end of the year.

United Kingdom (262)

The programme of the United Kingdom has been regularly discussed in these pages; a summary was given at the conference of British policy. The AGR programme is aimed at minimizing enrichment to possibly Pu spiking of a natural uranium feed. An alternative approach is the gas-cooled heavy water-moderated system which is also under investigation.

United States (1076)

Surveying briefly the very broad American concept, which has also been closely followed in these pages, 17 reactor years' experience of power plant has now been acquired and present annual expenditure on peaceful developments is in the region of $200 M. In the past year Shippingport has become operational; EBWR has produced power at three times the designed rate; OMRE has proved that in this system polymer replacement would amount to less than 1 mill/kWh; an advanced gas-cooled programme has been initiated; EBR-1 has been shown to be stable even under extreme reactor conditions.

In fuel element development a burn-up of 25,000 MWd/t (equivalent to 3 at %) had been obtained from Zircaloy-clad UO_2. MTR was now operating with a plutonium core, the SPERT experiments were providing valuable data on reactor transients and TREAT, which was designed to have a central flux of $3.5\ 10^{15}$ n/cm², sec and a rating of 1,000 MW-sec with a period of less than 20 m sec would provide information on fuel element melt-down behaviour.

America has vast resources of conventional fuel, but it is anticipated that competitive nuclear plants can be installed within the next decade and that by the end of the following decade total nuclear capacity will be approximately the same as present conventional capacity.

India (1624)

Uranium reserves totalling 30,000 tons are less than 10% of the thorium reserves and the programme is based on the progressive turnover to the thorium-U^{233} cycle. Present total power demand is doubling every five years but this will progressively relax to 10 years. Capital cost of conventional plant in India is high; hydro-electric schemes amounting to £130/kW. The reactor programme calls for 1,000 MW to be installed by 1966 based on natural uranium systems which can be built today for approximately £130/kW. Such stations will be directly competitive with conventional stations in high coal cost areas. The large capital investment necessary in mining and transport to exploit conventional fuels makes nuclear power developments peculiarly attractive in India.

The second generation of breeder reactors (either fast or thermal) will be called upon to generate 250 to 330 MW by 1967 and thereafter the third generation reactors starting in 1969 will be installed at an initial rate of 230 MW/an. These third generation systems will thus be required to have a total output of 1,600 MW by 1974, over 5,000 by 1979 and well in excess of 12,000 MW by 1984.

Cuba

An unexpected addition to the discussion came from Cuba, when it was announced that the National Bank for Social and Economical Development had decided that a nuclear power plant costing $15 M would be installed to supply the Pinar del Rio area. This plant would have an output of 22 MW and would be built by Mitchell Engineering-A.M.F. The plant is scheduled to be in operation in 1961 and will be of the pressurized boiling water type which is the speciality of this consortium.

Germany (1806)

At present three research reactors are in operation and one other is practically complete. Two of these are swimming-pool reactors and two water boilers. In addition, one Merlin and one DIDO type are under construction and a German-designed natural uranium reactor is scheduled for operation in late 1959. A large ETR-type test reactor is planned within the framework of Euratom. In addition to the BWR ordered by RWE from General Electric of America, consideration is being given to the Calder type, the heavy-water moderated and cooled reactor, the PWR, the AGR and the organic-cooled and moderated or organic-cooled and heavy water-moderated reactors.

It is not expected that contracts for German-designed stations will be finalized before 1961 and no significant nuclear generation is therefore scheduled before 1965, but about that time four or five nuclear plants, with a total capacity of 500 MW (E), will be brought into operation. It is possible, however, that prior to this two or three stations will be constructed to U.S. or U.K. designs but no decision has yet been reached. A major barrier to the exploitation of nuclear energy is the unwillingness of utility companies to provide the necessary additional capital outlay.

Italy (1363)

The programme of construction in Italy has previously been outlined in these pages. The results of the SENN tender examination are to be announced in the near future.

Australia (1093)

Plans at present are concentrated on building up experience and establishing an effective research unit. No formal power programme has yet been promulgated.

The President, Prof. Francis Perrin, at the opening session. With him are (left to right) Dr. Thomas Holenstein (President of Switzerland), Mr. Dag Hammarskjöld (U.N. Secretary-General) and Prof. Sigvard Arne Eklund of Sweden (Conference Secretary-General).

Japan (1318)

In Japan, with only limited conventional resources, nuclear power costs are already comparable with conventional costs. The present programme calls for 600 MW installed capacity by 1965 and 7,000 MW by 1975. The country is interested in the Calder type (tenders from three U.K. consortia are at present under consideration) the PWR, breeder reactors and fusion. Breeding is of broad interest as indigenous supplies of uranium will only be 200 tons/an. and the annual requirement by 1975 is anticipated to be 3,000 tons/an.

Netherlands (2435)

Government plans in the Netherlands are made as a guide only for the utility authorities, 80% of whom are public utilities. These have the ultimate responsibility for power generation. It is anticipated that 50% of the generation will be by fission reactors by 1975 and that these will correspond to 35% of the total installed capacity and will generate 15% of the total energy consumption of the country. In the assessment completed in 1957 the Calder type appeared to be the most promising with a generation of 13 to 14 mill/kWh as against 12 mill for conventional sources. In the interval capital costs have decreased and the price of coal has increased and nuclear generation now offers a generating prospect of 10 to 11 mill/kWh.

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1304 Prospects for the Use of Nuclear Energy in the Rumanian Popular Republic.
1318 J.A.E.C.; The Long-term Plan for Development of Atomic Power Reactors in Japan.
1363 Focaccia, B.; Nuclear Power Programme in Italy.
1593 Andrzejewski, S., *et al.*; The Perspectives of the Polish Nuclear Energy Programme.
1624 Bhahba, H. J., Prasad, N. B.; A Study of the Contribution of Atomic Energy to a Power Programme in India.
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2342 Cederwall, G.; The Swedish Nuclear Energy Programme.
2435 (Netherlands) Atomic Energy in the Netherlands.

Poland (1593)

Coal and lignite reserves in Poland are good and so also are uranium reserves. In addition there is no oil and little hydro potential and it is anticipated that by 1975 possibly no fossil-fired plants will be built. The first nuclear plant will be a natural uranium fuelled gas-cooled graphite-moderated reactor imported from Russia and scheduled for completion in 1962-63 and present costing anticipates that such reactor systems will be competitive in price by 1965. The projected programme calls for the installation of 800 MW by 1970 and 1,800 MW by 1975 by which time nuclear stations will be 10% of the nation's total installed capacity.

Rumania (1304)

It is not anticipated that nuclear generation will be significant until the early 1970s.

Spain (2336)

Financing will be a major problem in Spanish electrical developments but it is expected that after 1965 significant nuclear capacity will be installed amounting possibly to 6,000 MW by 1975.

Sweden (2432)

The Swedish atomic energy programme is distinguished by the attention to multi-purpose reactors. Six of these of capacity 75-100 MW are planned for the period up to 1965 in addition to one for electricity generation only of 100 MW. Potential for district heating reactors is estimated at 30 units of 30-60 MW, 10 units of 60-120 MW and 3-4 of over 120 MW in addition to a few 60-120 MW units for industrial plants. To satisfy increasing electrical demand in the period 1965-1975 an installed generating capacity of 2,000 MW is forecast.

Czechoslovakia

The U.S.S.R. is to construct in Czechoslovakia a 150 MW gas cooled heavy water reactor. Believed to be scheduled for commissioning in 1963 the plant is already in an advanced stage of design.

(*Translations page* 464)

Report from Geneva—2

Nuclear Fuel Resources

ON the North American continent ores which can at present be processed to yield uranium concentrate for sale at a price of $10 per pound can be considered economically workable. In the United States this implies concentrations as low as 0.1% although in general 0.16 to 0.2% are minimum values and the average is 0.28%. In Canada, due to easier separation conditions, concentrates as low as 0.75% are workable. Ultimate production from the explored reserves in the non-Communist countries (the Soviet bloc has declined to give information on either uranium production or uranium reserves) is estimated at approximately 1,500,000 tons U_3O_8 and on the basis of present geologic data an additional 2,000,000 tons of low-cost uranium could be developed in new areas within a reasonable period should the demand arise. It is estimated that the total annual production rate of non-Communist countries is in the region of 35,000 tons and in 1959 should approximate to 42,000 tons. The total annual value of the uranium concentrate production is at present approximately $750,000,000.

U.S.A. (1921)

Reserves are estimated at about 80 million tons of ore containing about 220,000 tons of U_3O_8. Production in the United States is approximately 15,000 tons U_3O_8 per annum and by 1960 will be at an annual rate in excess of 20,000 tons.

Heavy water production has been quoted as 1,000 tons/an.

Canada (221)

Reserves of immediately workable uranium ore are estimated at 400,000 tons U_3O_8. Production in 1957 was estimated to total 6,687 short tons, valued at 136,700,000 dollars; this was three times the production of 1956. Production rate by the end of this year is estimated at 13,000-15,000 tons/an.

France (1247)

The CEA has over the past few years undertaken a vigorous exploration in both France and Madagascar. The full extent of the reserves is not known but several rich areas have been found, for example, the Bois Noir deposit in the Forez region contains reserves to a depth of about 200 metres of at least 4,000 tons of uranium. Four mills have been set up to treat various grade ores. Production for 1958 will be approximately 550 tons; for 1959 it is estimated to be 750 tons; 1960, 1,000 tons, 1962, 15,000 tons. The territories of the French Union are also proving to be valuable areas and as an example the deposit at Nouana in Gabon is likely to be producing 300 tons of uranium per year by 1961.

The Madagascar deposits are producing only limited quantities of uranium and should be thought of as essentially thorium deposits. Known deposits are in the range of 6,000-8,000 tons of thorium. At present France is the largest producer of thorium in the form of thorium nitrate in the world. Present production totals 250-300 tons p.a.

South Africa (1107)

Reserves of uranium in South Africa are large and minimal estimates are in the region of 3,170,000 tons. Present production, largely as a by-product of gold-mining, runs at 6,200 tons p.a., and will rise to 6,400 tons by the end of 1959. The combined development agency has long-term contracts for purchasing in bulk nearly all present production and any further increase will be a function of demand.

Belgian Congo

One of the oldest known sources of high grade ores for radium production, the reserves in the Belgian Congo are now only 5,000-6,000 tons and these are being consumed at the rate of approximately 1,000 tons p.a.

Australia

Full exploration of the continent has been somewhat halted by the scale of world production as compared with demand, but present known developable reserves are estimated at 10,000 tons. Whilst production for 1958 is in the region of 600-700 tons, this will rise over the next year to about 1,000 tons of oxide per annum. Large thorium-bearing sand reserves are known and as in India and Brazil monazite export is restricted.

Sweden (2342)

Methods have been developed for the extraction of uranium from alum shale where the concentration is around 0.03%. Current production at Kvarntorp amounts to about 10 tons of uranium p.a., but a larger plant is to be built at Billingen and should produce 120 tons p.a. in 1964.

Japan (1359)

In Japan, although reserves are large the grade of the ore is in general low. No significant production can be anticipated before the early 1960s and it is expected that in 1963 production will be in the region of 50-60 tons, rising progressively over the years to a maximum annual rate of 200 tons in 1971.

Spain (1800)

Around 1,000,000 tons of low grade ore (concentrations from 0.1 to 0.8%) have been surveyed and some 4% ore has been located. The plant at Moncloa near Madrid is at present producing 10 tons of metallic uranium per year.

India (2516)

Workable uranium deposits are expected to yield some 30,000 tons total (although the country cannot yet be said to have been thoroughly explored) and steps are being taken to supply sufficient metal for fuel elements to meet the demand of the home nuclear programme. The known thorium reserves are in excess of 300,000 tons.

United Kingdom

Prospecting in Cornwall has revealed the existence of three areas where uranium might be recoverable. A more detailed exploration is, however, required before the extent and value of the deposits can be assessed.

(*Translations page* 465)

PAPERS LISTED

221 Griffith, J. W., *et al.*; Types and Ore Reserves of Canadian Radioactive Deposits.
1107 Pike, D. R.; Thorium and Rare-earth-bearing Minerals in the Union of South Africa.
1247 Mabile, J.; Development of the Uranium Mining Industry in France and in the French Union.
1359 Sato, M.; On the Results of Prospecting for the Promising Uranium Deposits in Japan.
1800 Perez, D. S.; The Mining of Uranium in Spain, Present Conditions and Prospects.
1921 Johnson, J. C.; Resources of Nuc'ear Fuel for Atomic Power.
2342 Cederwall, G.; The Swedish Nuclear Energy Programme.
2516 Ghosh, P. K., *et al.*; A Survey of Uranium and Thorium Occurrences in India.

Report from Geneva—3

Thermo-Nuclear Research

RESEARCH into the production and containment of high temperature plasmas is being conducted on a broad front throughout the world, predominantly, of course, in the U.S.A., the U.S.S.R. and the United Kingdom. Although the ultimate end is the production of a positive gain thermo-nuclear reaction, with all systems it is becoming increasingly clear that a great deal must be learnt about plasma physics and magneto-hydrodynamics before even the feasibility of such a machine can be demonstrated. Containment is without exception by magnetic fields but the shape of these fields and the method of production (formed in the plasma itself and/or external to it) varies considerably. In the same way the method of heating varies from experiment to experiment; examples are joule heating, adiabatic compression by pinching or magnetic pumping, shock waves, RF induction and injection from accelerators. Theoretical studies of plasma behaviour have shown that our understanding is very limited but certain fundamentals of plasma stability are now accepted. It seems clear that the pinch, stabilized by the type of field used in ZETA, can only produce a quasi-stable condition and that real stability in such a pinch requires that the magnetic field outside the plasma should at worst be constant and preferably increase with radial distance from the plasma.

TOROIDAL PINCH DEVICES

ZETA and SCEPTRE III (2, 3, 78, 1519)

These two British pinch machines have already been described in these pages (*Nuclear Engineering*, March, 1958). A recent development which should eliminate the problem of arcing between the linear sections and from the plasma to the liner concerns the substitution of the previously divided wall by stainless steel in a continuous form. This has already been tried in the Russian equivalent of ZETA but with the smooth wall used it is doubtful if plasma liner arcing has been eliminated. It is believed that with corrugated liners this problem can be resolved. Such a liner has already been installed in ZETA and it is hoped that a significant reduction in plasma contamination will result; this in turn should materially affect the plasma behaviour and lead to longer containment times. Peak currents of 300 kA are expected. Future modifications aim at 10^6 A from a 5 MJ condenser bank. The form of ZETA II will depend upon the results of current experiments but the machine will probably be built at Winfrith, the fusion team moving down in 1962-63.

Russian Torus (2226)

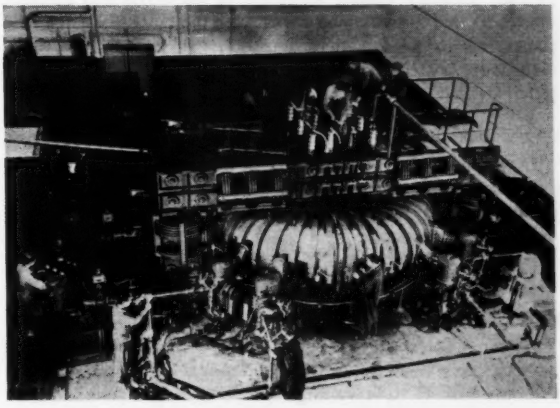
A series of tori have been built in the U.S.S.R., the largest of which has a tube diameter of 48 cm and a mean torus diameter of 1.25 m; the wall thickness of the chrome-nickel chamber is 0.02 cm. The torus is surrounded by a 2-cm thick copper case at a distance of 1.5 cm from the inner tube. Plasma is excited by coils wound equatorially on the torus (as in SCEPTRE but without the iron core) and the familiar axial stabilization field is applied. The half cycle pulse lasts for approximately 500 μsec generated by 150 μF charged to 5 kV.

UCRL (1064)

At Livermore, also, a series of tori have been tested, the largest of which is in quartz, 60 cm major dia, 10 cm minor dia fitted with a primary turn comprising a U-shaped ribbed (for strength) aluminium ring fed from a 0.5 MJ condenser bank. An axial magnetic field is generated by a split winding of copper braiding programmed to reverse the field on application of the drive pulse which has a rise time of 12 μsec. Theory predicts that in certain unlikely current conditions the reversed field effectively stabilizes the plasma.

EQUATOR—I and T.A. 2000 (1181)

The first torus built by C.E.A. in France at the Fontenay-aux-Roses laboratories of E.D.F. was of Pyrex, the major diameter being 78 cm and the minor diameter 8 cm. The glass tube is surrounded by a metal jacket of copper braid with a primary winding parallel to the equatorial plane. The torus is threaded by eight iron coils to increase the coupling. An externally produced axial magnetic field will support the plasma for a few tens of microseconds, the peak current being 50 kA.



ALPHA, the large Russian torus.

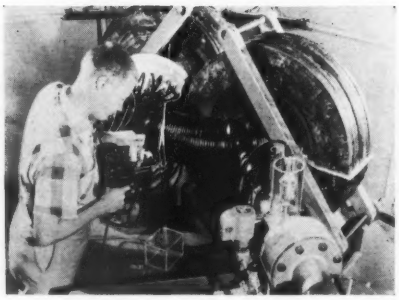
T.A. 2000 is a later and larger version built from aluminium with a stainless steel corrugated liner. Tube diameter is 26 cm and torus diameter 2 m and the ring is threaded by 16 iron coils.

PERHAPSATRON (1860, 2488)

The most recent of the Perhapsatron family at Los Alamos is S-4. This machine is toroidal, made of quartz with a 14-cm minor diameter, torus diameter of 70 cm, and wall thickness of 0.6 cm. The primary comprises a 1.25 cm-thick aluminium split toroid surrounding the discharge tube. The toroid is provided with two feed points (to double the volts/turn), fed in series from two condenser banks rated at 90 kV and storing 90,000 joule. A two-ton iron core of 0.002-in.-thick laminations in two sections links the primary and secondary. The stabilizing field (maximum 4,000 gauss) is pulsed, an equatorial split being provided in the aluminium primary in addition to the division for the feed points to allow rapid build-up of the field. Pulses of several tens of microseconds are achieved.

Sweden (147)

Two toroidal pinch machines have been built at Uppsala. The smaller, made of aluminium, has a minor diameter of



The "Perhapsatron" S-4 at Los Alamos.

8 cm and a major diameter of 60 cm. It is air coupled and activated by a condenser bank of 1,640 μF and charged to 7.5 kV giving a current pulse extending over a quarter of a cycle corresponding to 70 μsec. Currents in the machine of 200 kA have been measured. The second machine is powered from a bank capable of supplying 1 MJ in a torus 28 cm minor diameter, 130 cm major diameter, made of either metal or porcelain surrounded by metal. Two primaries are provided, one gives an induced voltage in the direction of the axis of the torus body induced by 40 coils tightly packed together, each consisting of four separate copper windings of six turns and at right angles to this a coil of 80 turns. The two windings can be connected in series or in parallel. In Sweden work is also being performed on discharges in linear tubes to study pinch behaviour.

General Atomics—TAERF (1062)

In addition to work on linear discharges, experiments are being made at this U.S. laboratory on a torus of 6 cm minor diameter, 30 cm major diameter. This is being used in general investigation work on the pinch discharge.

LINEAR PINCH DEVICES

COLUMBUS Family (1860)

At the Los Alamos laboratories a series of linear pinch devices have been built to study pinch behaviour.

Columbus II, a very high power pinch machine, generates plasma between electrodes in a tube 30 cm long by 10 cm diameter; supply is from 25 0.8 μF condensers rated up to 100 kV and discharging a peak current of 800 kA with a rise time of 2.2 μsec. Axial magnetic fields are initiated by external windings.

Columbus S-4 is a lower powered device with a tube diameter of 13 cm and a tube length of 61 cm. Power is supplied from a condenser bank of 75 μF rated at 20 kV giving a peak current of 250 kA in 6 μsec. Tube material is alumina and contamination of the discharge appears to be remarkably low. This therefore is a valuable experimental machine for studying the fast pinch and its stability criteria.

Columbus T-1 is a straight discharge tube 6 m long by 15 cm diameter having 1.6 cm thick Al walls divided in 5 cm-long insulated sections. In this device, built to test the effect of metal walls on a pinch, a particular mode of spiral instability has been demonstrated.

Germany (1056)

Theoretical work in thermo-nuclear reactions was begun in 1956 and various linear discharge machines have been built. In February of this year consideration was given to the construction of a toroidal discharge but further work will be held up until the transfer of the Max Planck Institute to Munich is complete.

Russia (2302)

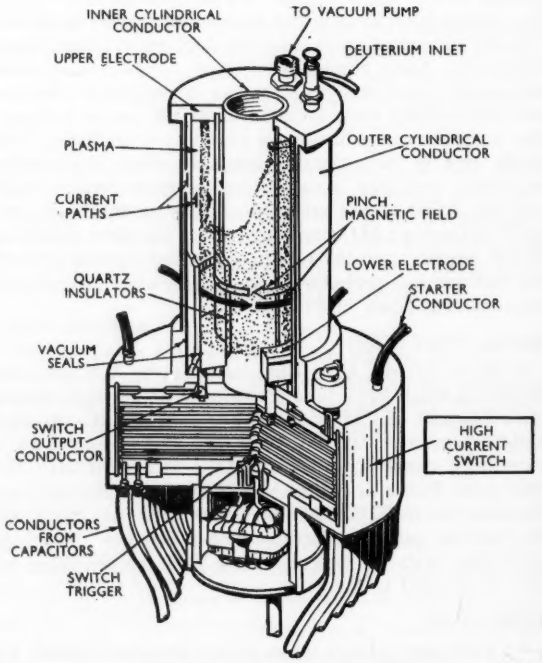
A number of fast pinch linear machines have been built. One programme is concerned with investigating pinch discharges in chambers 60 cm i.d. by 17.5 cm high made of porcelain using flat aluminium electrodes; in another, copper electrodes were used in a chamber 4.7 cm high and 18.5 cm i.d. and the third used similar electrodes in a tube of the same diameter and 25 cm high. The behaviour of the plasma was investigated by the usual probes, including Rogovsky coils.

A.W.R.E. (1460)

Similar work is being undertaken at A.W.R.E. Aldermaston on the linear pinch. Two power banks have been built to initiate the discharge, characterized by highly synchronized parallel spark-gap switching. In the first of these, condensers of 121 μF charged to 10 kV are capable of giving a short-circuit current rise of 1.2×10^{12} amp/sec and a peak short-circuit current of 1.1×10^{6} A, the bank storing 6 kJ. The larger, 45 kJ bank of 100 μF charged to 30 kV, can deliver a short-circuit current of 3.6×10^{6} A with a rise time of 5.5×10^{12} amp/sec. The application of stabilizing fields has indicated plasma characteristics which are not in accord with other published results of similar work. Measurements on the A.W.R.E. machine are consistent and reproducible; the divergence is not fully understood.

TRIAX (1064)

The plasma in this machine, built at UCRL, is formed in cylindrical geometry between annular electrodes. The return current passes through insulated concentric cylinders on the inside and the outside of the discharge chamber. The pinch plasma so formed approximates to a sheet which has, if infinite, neutral stability. Peak currents of 6×10^{5} A have been achieved from a total energy supply of 10^{4} joules and under suitable conditions up to 10 oscillations have been discerned lasting for about 3 msec with no sign of instability. In attempts to obtain temperatures sufficiently high for thermo-nuclear reactions, lower initial gas



TRIAX—an annular pinch machine.

pressures (down to 75 μ) and higher currents up to 1.5×10^6 A are being tested.

At the same laboratories various types of linear electrode discharges are also being used for examining plasma behaviour.

COLUMBUS T-2 (1860)

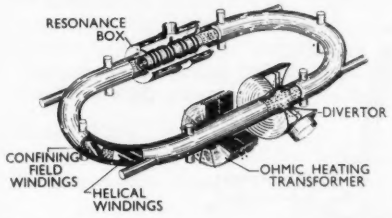
At Los Alamos attempts are being made to produce a pinch at a much lower particle density than is possible by self induction, by axially injecting a plasma into a current carrying chamber (for mechanism see PAM) 360 cm long by 90 cm diameter which contains a strong axial magnetic field. When the plasma bridges the two ends the pinch is formed. The original subdivided wall is being replaced by a stainless-steel bellows assembly and it is hoped thereby that arcing can be eliminated.

EXTERNAL FIELD CONTAINMENT

All the machines discussed up to this point have produced pinched discharges, the pinch adiabatically heating the plasma and being caused by the magnetic pressure of the plasma's own field. High temperatures can be built up in plasma without a pinch occurring and externally generated magnetic fields are then used to prevent contact between the discharge and the container walls.

STELLARATOR (2170)

The Stellarator devised by Princeton University really represents a family of closed machines characterized by the application of high external magnetic fields. To mini-

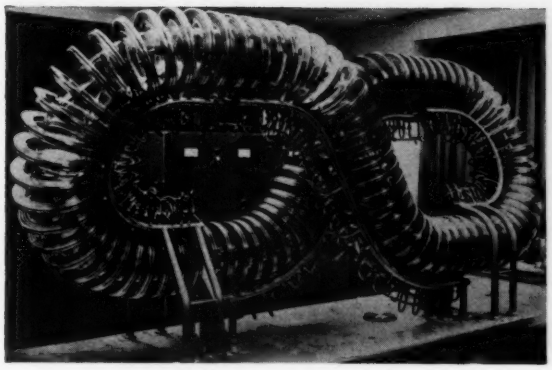


The B-65 Stellarator.

mize radial drift of the ions, a twist in the lines of force is required, this rotational transform being achieved either by twisting the ring into a figure eight or by superimposing helical windings on the axial field windings. The twist so produced evens out inhomogeneities in the field and prevents drift to the inner walls. Various systems of heating the plasma and various configurations of magnetic field are under investigation. In one embodiment of the system with a race-track geometry, initial heating is by joule heating through an iron core transformer and this is followed by "magnetic pumping" which consists in imposing an oscillating field; successive expansion and contraction of the plasma permits energy to be fed in.

A method which overcomes the screening of the electron shield involves the imposition of an RF field at a frequency corresponding to the ion cyclotron resonance. This has been successfully demonstrated in the B-65 Stellarator. The B-65 is a race-track discharge tube 207 in. long made from 0.083 in. stainless steel 4 in. in diameter; it includes a diverter which has the effect of creaming the edge of the plasma (which is not pinched) and differentially pumping out the contamination products.

In the ion cyclotron resonance experiment, a ceramic tube 21 in. long is inserted, surrounded by an RF coil, the two ends of which are grounded; the feed enters at a centre tap. The azimuthal RF current alternates in direction every two and a half turns, the spacing of the coils corresponding to the ion cyclotron propagation wave-length. In addition, small magnetic mirrors are provided at the ends.



The "Figure 8" Stellarator.

In Russia also (2211), heating by ion cyclotron resonance techniques have been successfully demonstrated. The efficiencies achieved are impressive and significant energy inputs to the plasma are reported.

A larger machine—the Model C. Stellarator, is to be built at Princeton; site work has already begun. This will also be a race-track shape, the mean radius of the ends being 43 in. and the straight sections 100 in. (1,200 cm round). Tube diameter is increased to 8 in.

To avoid the decrease in field outside the plasma, field configurations such as the picket fence are being investigated both at Los Alamos and in Russia. In this a concave plasma surface is produced, i.e., with a multi-cusp profile (1064).

An alternative scheme is being investigated at UCRL which utilizes the not insignificant density of ions outside the plasma and creates by external windings a field in the gas external to the plasma but within the confining chamber. The overall process here has been called the screw dynamic pinch which has been demonstrated in linear machines.

Oscillating Field Machine (2225)

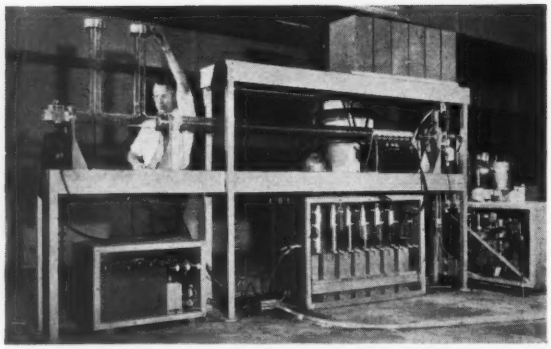
A Russian project to stabilize a ring plasma by oscillating magnetic fields maintained in a direction perpendicular to the face of the disc is under way. Equilibrium conditions are similar to those found in betatrons and in the experiments plasma containment has been observed. The plasma appears to form in clumps and expands and collapses within the chamber confines and is held by the magnetic field away from the walls. The induction and stabilizing fields are formed by a system of ring-shaped conductor strips round the periphery and two copper rings on both sides of the disc.

MIRROR COMPRESSION

At UCRL a programme of research is being conducted on the magnetic compression of initially low-temperature ionized gas. In these experiments a burst of gas is introduced into a high vacuum where it is "manipulated" by magnetic fields. So far experiment and theory are in excellent agreement and it is proposed to increase pressures to determine where and how discrepancies (if any) arise.

TABLE TOP (377)

In the latest version of this machine gas is injected into a glass tube from three ganged titanium guns spaced at 120°. The tube is surrounded by two coils in mirror geometry which are programmed to trap the gas as it arrives at the centre of the tube and compress it. A small axial field is applied initially and the mirror is impressed with a rise time of 500 μsec and short circuited to give a decay time of 20 msec, total power being 0.5 MJ. Stable plasma lasting for several milliseconds has been observed, the diffusion of the ions being predictable on collision diffusion theory.



PAM (Plasma Acceleration Machine) at Los Alamos.

TOY TOP (377)

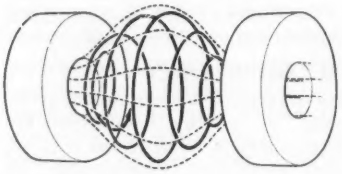
This is a three-stage compression machine in which the gas (at 50 eV) injected from multiple Ti guns is compressed by mirror fields in a tube 10 ft long × 8 in dia., transferred by the field which progressively moves down a set of axially disposed coils into a 5 ft 9 in.-dia. section and finally into a 1 ft 3 in.-dia. section. Very high overall compressions are possible and the transfer has the effect of removing contamination from the plasma.

FELIX (377)

Felix was built to prove that with the mirror geometry long particle confinement times are possible. This has been clearly demonstrated but unfortunately the large loss immediately on injection prevents high densities.

SHOCK WAVES

High speed magnetic compression can form shock waves in plasma which result in turn in increasing the temperature of the plasma. One such machine (345) in the U.S.N. Research Laboratory, Washington, is provided with a coil system surrounding the shock tube in which fields of up to 500,000 gauss can be generated with currents of 1.5-8 × 10^6 amp. Energy is supplied from a total capacity of 1,430 μF storing 285 kJ. In the device simultaneous shocks are given to two coils at each end of a vacuum tube and these meet in the centre forming a stationary plasma which mixes and is held in a mirror geometry field.



Magnetic bottling in mirror geometry.

SCYLLA (356, 1860)

Scylla is a shock-wave machine at Los Alamos in which the power input consists of a single turn coil with the i.d. greater in the middle than at the ends to provide a mirror geometry at the same time as imposing a magnetic shock. The coil is energized from a bank of condensers, total capacity 8.8 μF rated at 100 kV and the circuit is such that a damped oscillation of 200 kc/sec is produced in the alumina tube. Neutrons do not appear in the first current half cycle, probably due to incomplete ionization and to trapped magnetic fields. In the second, third and fourth current maxima, however, they are observed. The shape of the mirror coils is important as no neutron generation occurs with uniform fields.

PAM (1860)

PAM is a device for studying the acceleration of shock induced plasma. A mechanical fast acting valve admits pulses of deuterium to the end of the tube into the field of a shock coil energized by a 0.8 μF condenser charged to 60 kV. It then passes through a series of coils, giving a travelling wave acceleration. An axial magnetic field is imposed on the tube and momentum transfer from the plasma is measured by a ballistic pendulum. Plasma velocities of 6 M cm/sec have been recorded.

Attempts have been made in Russia (2298) and there is a suggestion that the same technique has been tried at A.W.R.E. Aldermaston to induce thermo-nuclear reactions by chemical explosions. In the Russian experiment neutrons were observed which could scarcely have been derived from electrically accelerated particles. The explosion destroyed the apparatus. There would appear to be no practical method of using this system in a power producing machine.

DC MACHINES

Probably the most exciting thermo-nuclear machines which have been discussed at the Geneva Conference are the mirror machines designed to contain plasma injected from accelerators.

DCX (344)

In the Oak Ridge device a 0.5 mA beam of deuterium molecular ions at 600 keV is injected into a vacuum chamber enclosed by magnetic mirrors. The beam is arranged

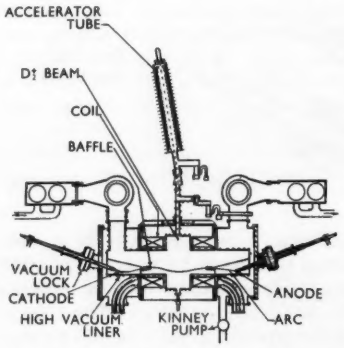


Diagram of DCX machine.

to strike a carbon arc formed near the centre of the mirror geometry. A high degree of dissociation takes place, the uncharged deuterium ion is lost to the system and the charged ion continues to orbit within the mirror geometry, the diameter of the orbit being half that of a molecular ion in the same field. The carbon arc has been developed from gas arcs and is struck between two carbon electrodes, the path of the arc being defined by the magnetic field. Arcs of many feet in length can be formed in high vacuum. In addition to dissociating the molecular beam the arc also has the property of cleaning the system and is in fact an effective high-speed pump.

Deuterium ions are lost to the system by the leakage through the ends of the magnetic bottles and by collision with neutral atoms. In the DCX machine "burn-out" of the neutral atoms leaking into the system has not yet been achieved but steps are being taken to increase the injection current, and improve the initial vacuum when progressive burn-up of the neutral atoms should be possible.

A larger machine, ORION, is being constructed to contain also the charged fusion products formed. This will still use a carbon arc with a central field of 35,000 gauss. It should be noted that power consumption will be of the

order of 15 MW. A continuous (not positive gain) thermonuclear reaction machine could be in operation utilizing this system in two years' time.

A further possible development concerns the structure of the arc, which is hollow and can be produced by deuterium and could, therefore, at least in principle, be caused to surround completely the plasma. Should this prove to be feasible, the ingress of neutral atoms could be virtually eliminated.

OGRA (2298)

In Russia a similar direct-current continuously operating device is in operation. The machine is considerably bigger than DCX, the distance between the centres of the magnetic mirrors being 12 m and the vacuum chamber diameter 1.4 m. The field strength of the centre of the vacuum chamber can be raised to 5,000 gauss and in the mirrors to 8,000 gauss. No arc dissociation is included, however, and the efficiency of the dissociation must be small. It is expected soon, however to increase the current in the injection system to several hundred milliamps.

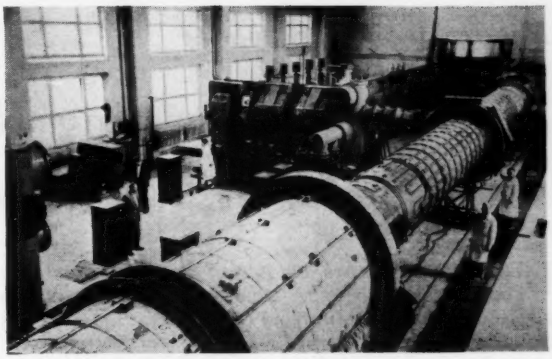
ROTATING PLASMA

IXION (1860)

Ixion, built at Los Alamos, is a mirror machine with an axial magnetic field combined with a radial electric field which rotates the plasma. Plasma is initially injected along the axis of the mirrors from a generator similar to that used in PAM, in which a high-speed valve permits the entry of a pulse of deuterium, which is then heated and driven into the chamber by a shock coil. The rotation of the plasma induced by the perpendicular electric and magnetic fields appears to enhance the containment of the mirrors and although breakdown at present limits the value of the process further development is in progress.

Russia (2298)

Magnetic bottle containment of plasma generated by a discharge struck between two electrodes at the ends of the bottle and with a radial electric field imposed between the plasma so formed and the walls of the chamber has been examined in Russia in a chamber 2 m long with central fields of 8,500 gauss rising to 12,000 gauss in the mirrors; plasma has been stabilized for several milliseconds. The main aim of this experiment is the determination of the life time of fast ions for various ion concentrations in the magnetic system.



Russia's OGRA experiment.

UCRL (1064)

In the device built at UCRL, a radial electric and an axial magnetic field are used to set the plasma in azimuthal drift motion. A transient radial current flows during the acceleration stage which pinches the plasma axially away from the walls. Axial magnetic field used has been of the mirror type and when the plasma is developed the centrifugal force associated with the rotation holds the ions away from the axis and traps them in the region of the bulging field. The plasma does, however, progressively lose energy but the exact mechanism is not known.

ASTRON (2446)

A novel approach towards plasma containment investigated by UCRL involves the production of a high current rotating relativistic beam of electrons which, providing it is given sufficient energy, will form a stable layer. This layer acts like a solenoid and in combination with an externally applied solenoid creates a configuration of closed magnetic lines. The electrons progressively lose energy to the ions and the system holds promise of producing very high temperatures.

Homopolar (1329)

In Japan a combination of magnetic homopolar generator and pinch machine has been suggested in which the rapidly rotating discs are arranged face to face and perpendicular to a high magnetic field. The two discs rotate in opposite directions and the currents set up can create a pinch in the gas in the gap. Preliminary experiments on this machine are under way.

Other Work

RF containment of plasma has also been investigated by Russia but, although the method would appear to be theoretically feasible, practical demonstration of the system is difficult (2298).

To investigate plasma instability a programme of model examination is being carried out in Sweden (1708). High currents are passed through a falling column of mercury and the deformations of the stream photographed.

(*Translations on page* 465)

PAPERS LISTED

2 Thompson, W. B., *et al.*; Theoretical Problems Associated with Zeta.
3 Allibone, T. E.; A Review of the Controlled Thermonuclear Research at the A.E.I. Research Laboratory.
78 Thonemann, P. C.; Controlled Thermonuclear Research in the U.K.
147 Siegbahn, K.; Toroid Discharges in Deuterium with External Magnetic Field.
344 Bell, P. R., *et al.*; Description of the Oak Ridge Thermonuclear Experiment.
345 Kolb, A. C.; High Temperature Plasmas Produced by the Magnetic Compression of Shock Pre-heated Deuterium.
356 Elmore, W. C., *et al.*; Neutrons from Plasma Compressed by an Axial Magnetic Field (Scylla).
360 Stix, T. H.; Experiments with Ion Cyclotron Resonance.
377 Post, R. F., *et al.*; Summary of UCRL Pyrotron Programme.
1056 Biermann, L.; Report on Some Recent Work in the Field of Controlled Thermonuclear Fusion in Germany.
1062 Kerst, D. W.; Joint General Atomic-TAERF Fusion Programme.
1064 Colgate, S. A., *et al.*; The Livermore Shock and Pinch Programme.
1181 Aymer, R., *et al.*; Studies on Controlled Fusion in France.
1329 Miyamoto, G., *et al.*; Proposed Methods of Obtaining Stable Plasma.
1460 Curran, S. C., *et al.*; Studies of High Current Gas Discharges at High Rates of Build-up.
1519 Thonemann, P. C., *et al.*; The Design and Performance of Zeta.
1708 Dattner, A., *et al.*; A Liquid Conductor Model of Instabilities in a Pinched Discharge.
1860 Tuck, J. L., *et al.*; Review of Controlled Thermonuclear Research at Los Alamos.
2170 Spitzer, L., jnr., *et al.*; The Stellarator Programme.
2211 Sinelnicov, K. D., *et al.*; Experimental Research on High Frequency Properties of Plasma and Magnetohydrodynamic Shock Waves.
2212 Kadomtsev, B. B., *et al.*; Plasma Stabilization by Means of Non-uniform Magnetic Fields.
2225 Osovets, S. M., *et al.*; Investigating the Equilibrium Plasma Loop in a Transverse Magnetic Field.
2226 Dobrokhotov, E. I., *et al.*; Investigations on Plasma Heating in a Toroidal Chamber.
2298 Artzimovich, L. A.; Investigations on Controlled Thermonuclear Reactions in the U.S.S.R.
2302 Komelcov, V. S., *et al.*; Creating Strong Discharges in Deuterium.
2410 Teller, E.; Peaceful Uses of Fusion.
2446 Christofilos, N. C.; The Astron Thermonuclear Reactor.
2488 Phillips, J. A., *et al.*; Operational Characteristics of the Stabilized Toroidal Pinch Machine—Perhapsatron, S-4.

Report from Geneva—4

Interesting Reactor Designs

1. The High-temperature Gas-cooled Reactor

DESIRABLE features of future power reactors* are compactness, operating temperatures high enough to give superheated steam around 600°C (approx. 1112°F); a fissile/fertile mixture for fuel, with a high conversion ratio, and a long burn-up period.

The first two conditions call for a fuel surface temperature of around 1000°C, which necessitates fuel in the form of oxide or carbide and high temperature canning materials —if canning is used, although it appears feasible to employ a mixture of fissile, fertile, and moderator materials, without metallic cladding. Suitable moderators would be graphite and beryllia, graphite being selected for the early work. This, of course, rules out carbon dioxide as a coolant for high temperature work. The fuel considered as a possibility is a mixture of U^{235} and Th^{233}, and the form of fuel element envisaged in an almost homogeneous mixture of fuel and graphite surrounded by a layer of inert moderator to act as a can.

Fission product containment with such an arrangement would be exceedingly difficult and it is proposed that the fuel element shall be hollow with a small inlet vent and the inside kept at a lower pressure; the fission product gases being, in effect, pumped out of the element through a trap where the gaseous products can be held up while decay takes place and the entrained solids permanently absorbed.

A further concept of this type of reactor is the use of a gas turbine in the coolant outlet duct, driving a circulator in the inlet duct. The heat drop introduced by the turbine would still enable high steam temperatures to be obtained, with a considerable reduction in pumping power.

Present activities in the high temperature field include a design study of a 10 MW plant, and a zero-energy experimental reactor. which is at present under construction at A.E.E. Winfrith Heath.

ZENITH

ZENITH, the zero-energy high temperature experiment† designed by A.E.R.E., and under construction by the General Electric Co. Ltd., is intended to solve a number of problems for larger reactors, and is expected to be in operation early in 1959.

It consists, briefly, of a pressure vessel enclosing a sub-critical core and reflector, with arrangements for heating and cooling the circulating gas (nitrogen) to obtain the necessary working temperatures, together with the necessary control gear and charging mechanism. Figs. 1 and 2 show the general arrangement of the plant and a section through the reactor vessel.

The pressure vessel of cylindrical form, with a conical lower end and a flat cover, has an overall height of 17 ft 2 in. (523.2 cm) and an internal diameter of 10 ft 7½ in. (323.8 cm). The major portion of the vessel, which has to operate at 400°C, is fabricated from Si-killed boiler plate to BS1501-154 Grade B; the top cover which operates at low temperature (56°C) is fabricated from boiler plate to BS1501-151 Grade B. The cover, and the lower core and inlet, are protected by insulation, contained in gastight steel boxes. To prevent undue stress on these during evacuation of the vessel prior to gas filling, the boxes are connected to a separate vacuum system and simultaneously evacuated. During operation vents to atmosphere are provided for these boxes to prevent undue pressure rise.

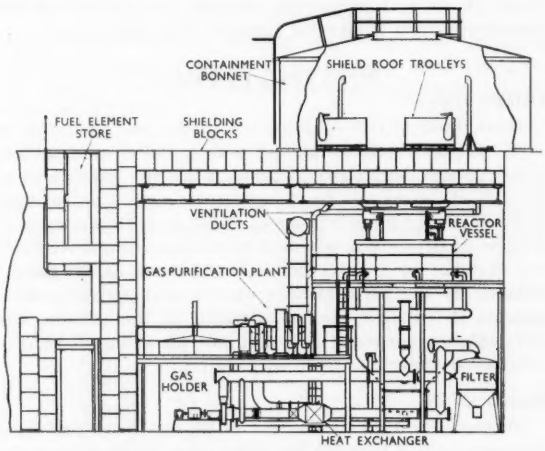


Fig. 1.—General arrangement of ZENITH.

Gas Circuit

Two alternative flow rates, normal operation and a high rate for cooling-down purposes, are available by a twin motor drive to the main blower, the motor ratings being 3 h.p. at 970 r.p.m. and 30 h.p. at 2,800 r.p.m., and the selection by scoop-type fluid coupling.

The hot gas from the heater passes upwards through the core, and enters a mixing zone, where it is mixed with additional cool gas, afterwards passing downwards through the reflector and out at a number of nozzles into a ring main and through a ceramic filter and to a double-tube type heat exchanger where it is cooled by water sufficiently to prevent trouble with the blower. Two auxiliary circuits are provided, one for continuous sampling and analysis, and the second for continuous purification and removal of hydrogen water vapour, CO and CO_2 from a proportion of the main gas flow which is circulated through the purification by-pass by a booster pump. A gasholder is provided to compensate for the volume changes as the reactor is heated up or cooled down.

To obtain a more accurate simulation of the temperature distribution of a power reactor, it is necessary to cut down the heat radiated from the core to the reflector. The insulating shield utilized for this purpose consists of a 2 in. space, formed between a wall of 1½ in. interlocking graphite slabs and the reflector proper, the space being filled with pelletized lampblack, chosen for its nuclear qualities, which resemble those of graphite.

* "The Possibilities of Achieving High Temperatures in a Gas-cooled Reactor." Paper 314, by L. R. Shepherd, *et al.*

† "Problems in the Design and Manufacture of a High Temperature Gas-cooled Zero Energy Reactor." Paper No. 1463, by K. J. Mitchell, *et al.*

Core

The core consists of 235 fuel elements arranged on a 3-in. triangular lattice. The fuel elements, shown in Fig. 3, are composed of stacked fissile, fertile, and spacer pellets, comprising enriched uranium, thorium ceramic and graphite, respectively. These discs are enclosed in a graphite tube, with a hexagonal head having chamfered corners so as to leave a $\frac{7}{8}$-in. dia gas channel when assembled in the lattice. The elements are supported on a support plate or grid which, since it operates at 950°C is made of Nimonic 90. This, of course, contains some 18-20% cobalt and, to reduce its activation, each fuel element stands on a boron steel disc. These discs cover some 75% of the plate area: most of the remainder is drilled away to form gas passages.

The reflector consists of graphite blocks, totalling some 26 tons with a number of holes, mostly near the inner edge, for control and depletion rods, as well as for flux and temperature measurements. Accommodation is provided for 20 control elements and 10 depletion rods, an extra six depletion rods are installed approx. one diameter behind these.

The overall plant control automatically holds the main parameters at the desired values, freeing the operator from routine work. Thermocouples maintain the gas temperatures at any desired value; an over-riding control responding to the mass flow, protects the heater by preventing a greater heat input than the gas flow will remove. The heat exchanger is provided with by-pass arrangements to ensure a reasonably constant inlet temperature to the blower.

TABLE 1—General Particulars of Zenith

Core diameter, active	4 ft 0 in. (121.9 cm)
Core diameter, over reflector	10 ft 6 in. (320 cm)
Core height, active	4 ft 0 in. (121.9 cm)
Core height, over reflector	8 ft 0 in. (243.8 cm)
Weight of graphite reflector	26 tons
No. of elements	235
Lattice pitch	3 in. (7.62 cm)
Thermal flux (max.)	10^{13} n/cm², sec
Power (max.)	100 W
Gas flow, normal working	3,000 lb/h
Gas flow, cooling down	10,000 lb/h
Working pressure	18 in. w.g.
Inlet temp. (to heater)	400°C (752°F)
Inlet temp. (to reactor)	950°C (1742°F)
Time to heat up or cool down	48 hours

Containment

The reactor and its auxiliaries are contained in a concrete pit, with a concrete block wall 4 ft thick separating the reactor from the rest of the pit. The roof of the enclosure is formed of concrete blocks supported on a steel grid, and an opening is provided for charge or maintenance purposes; shielding of this hole consists of a pair of removable trolleys. This part is surrounded by a steel "bonnet" or gas-tight containment to which access can only be obtained through an air lock.

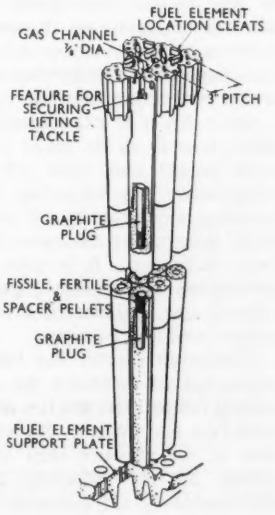
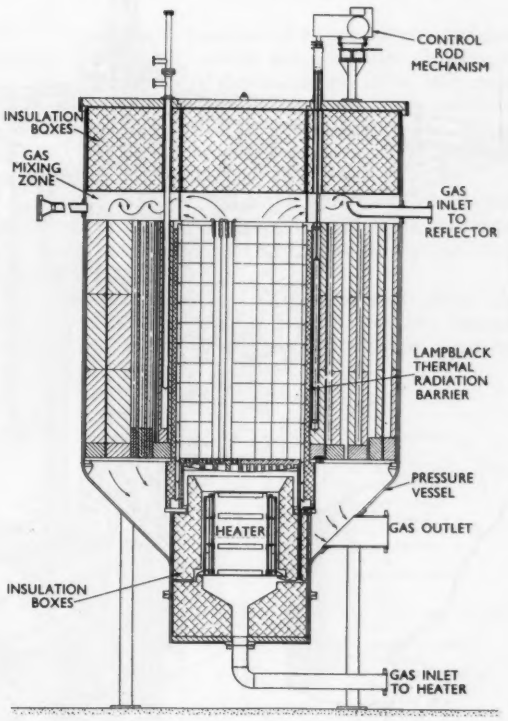


Fig. 3.—Fuel element for ZENITH.

Fig. 2.—Section through reactor vessel.



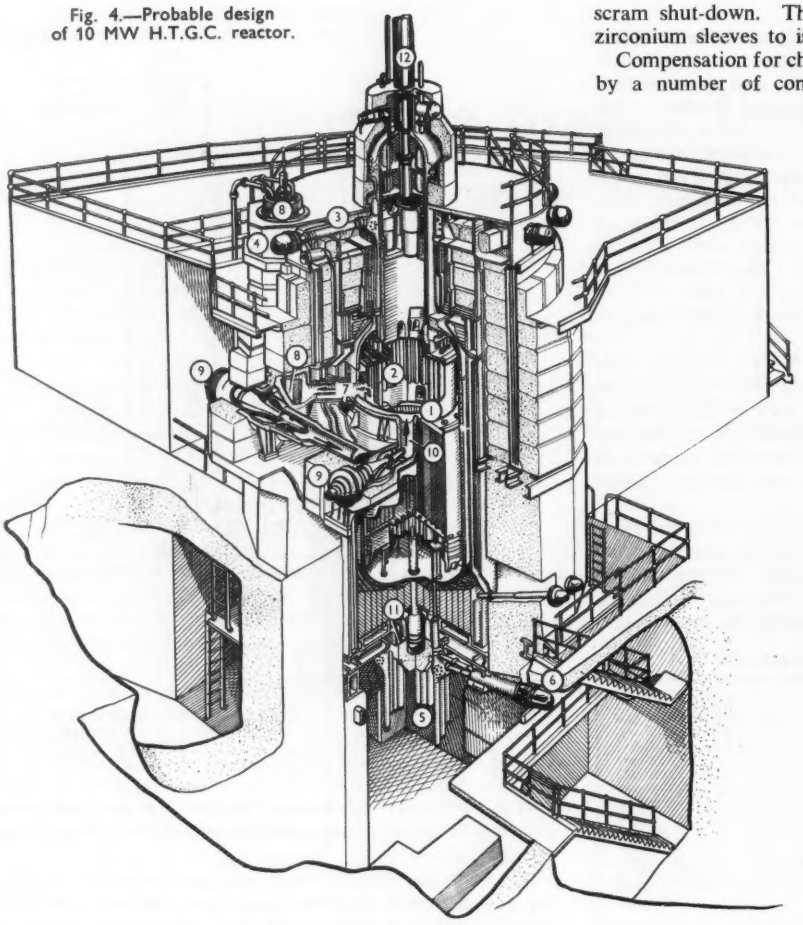
Although the reactor vessel and gas circuit are lagged, there is still some 36 kW of heat to be removed from the pit. Ventilation is provided by two 3,000 cu. ft/min axial-flow extractor fans maintaining a slight negative pressure in the enclosure, a proportion of the extract air being taken from the bonnet. Incoming air is filtered, by a replaceable glassfibre filter; a high efficiency paper filter deals with the effluent air before discharge to atmosphere.

PROPOSED 10 MW REACTOR

The proposed 10 MW reactor which is under study at Harwell, would take the general form of Fig 4, general parameters being given in Table 2. The core, an approximate cylinder some 4 ft in diameter and 4 ft long (without reflector) is made up of 61 fuel elements, each comprising seven hexagonal rods, or tubes, generally similar in appearance to those used in the zero-energy reactor. The assembly of the seven rods, in the form of a hexagonal cluster, is fitted with a lifting block at the top end, a porous plug is provided in the top of each rod to admit the scavenging gas flow. At the bottom, the rods are joined together on a mounting block, provided with gas passages which join the exhaust holes in each rod to a common port which sits on a hollow mounting spike from which the gas is extracted to the scavenge system. Part of a fuel element is shown in Fig 5.

The core, which with this construction has a voidage of some 15%, is surrounded by a graphite reflector with an overall diameter of 10 ft 6 in., made of graphite columns 8 ft high, with about 5% coolant voidage. Both the fuel elements and the reflector columns are pivotally mounted, the reflector closing on the core and being provided with

Fig. 4.—Probable design of 10 MW H.T.G.C. reactor.



KEY

1. Pressure vessel.
2. Core.
3. Control rod mechanism.
4. Control rod driving motor.
5. Compensating rod and mechanism.
6. Compensating rod driving motor.
7. Hot gas outlet.
8. Heat exchanger.
9. Gas circulators.
10. Cooled gas inlet.
11. Gaseous fission product extraction manifold.
12. Part of fuel element flask.

suitable restraint so that, although the fuel elements are firmly held, free expansion is permitted.

Control

The control rods, 30 in number, move in vertical channels near the inner surface of the reflector. They are arranged for lifting by cable drives, with magnetic clutches for scram shut-down. The control actuators are enclosed in zirconium sleeves to isolate them from the hot gas.

Compensation for changes in reactivity might be arranged by a number of compensating rods placed in a circle outside the main control rods, and raised and lowered from below: these are shown in the illustration (5 in Fig. 4) but it might be decided to use a burnable poison instead.

TABLE 2.—General Particulars of Proposed 10 MW H.T.G.C. Reactor

Core diameter, active	approx. 124 cm (4 ft 0 in.)
Core diameter, over reflector	approx. 320 cm (10 ft 6 in.)
Core height, active	approx. 124 cm (4 ft 0 in.)
Core height, over reflector	approx. 248 cm (8 ft 0 in.)
U^{235}	14.2 kg
Atomic ratio, graphite—U^{235}	2860
Atomic ratio, Th—U^{235}	7.4
No. of fuel elements (7 rods per element)	61
Inlet gas temp.	350°C
Outlet gas temp.	750°C
Mean temp. of graphite	1100°K (827°C)
Mean temp. of fuel insert	1300°K (1027°C)
Reactivity	
Initial excess reactivity (10 MW)	5.9%
Excess reactivity available in cold (300°K) clean condition	11.3%
Reactivity absorption due to thorium temp. (300°K to 1300°K)	−2.0%
Reactivity absorption due to moderator temp. (300°K to 1100°K)	−5.5%
Reactivity released by heating reflector through mean temperatures of 375°K (side) and 500°K (ends)	+2.1%
Reactivity associated with Xe in equilibrium	2.5%
Reactivity associated with Sm in equilibrium	0.7%
Maximum reactivity absorption by Xe, 6.5 hours after shut-down	4.0%

Fig. 5.—Part of fuel element.

Coolant

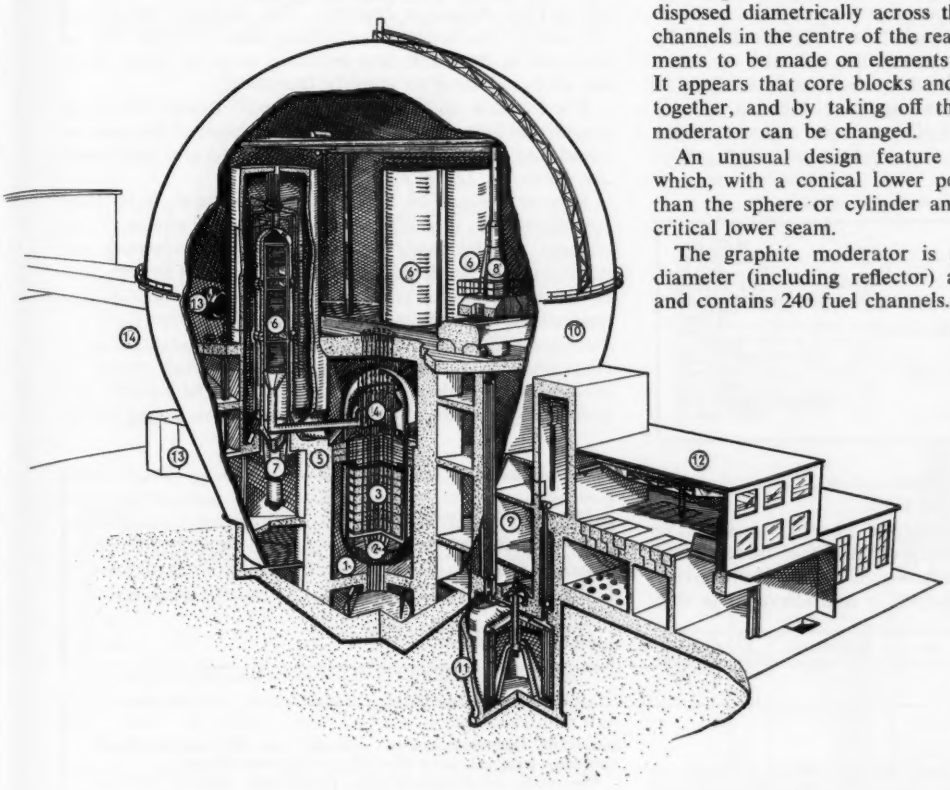
The coolant specified for this study is nitrogen at about 150 p.s.i. The gas at about 350°C enters by side ports (10 in Fig. 4) and flows down the side walls of the vessel afterwards passing up through the core and emerges into a Nimonic-lined chamber at a temperature of around 750°C and passes by a side duct to the heat exchanger from which it emerges into the circulation units.

Since this is an experimental study, no attempt at power generation is to be made and the heat exchanger is a water-cooled unit, from which the water emerges at a temperature not exceeding about 75°C (about 168°F), avoiding any necessity of pressurization and, due to the large temperature difference, giving a comparatively small heat exchanger. It is also not considered worth while developing a free-running gas turbo-blower unit for such a small size, and electric drive would be used with sealed motors and gas bearings.

The entire reactor has been designed so that no part which has to withstand the coolant pressure is subjected to high temperature gas (i.e. over 350°C); the Nimonic-lined chambers and ducts at the top of the reactor do not form part of the pressure shell and are themselves externally cooled by the incoming gas. The reactor itself is surrounded by a water-cooled shielding system.

A.G.R.*

General arrangement of A.G.R.



KEY

1. Reactor vessel.
2. Cool gas inlet.
3. Core.
4. Hot gas outlet.
5. Ducting.
6. Heat exchangers.
7. Blower.
8. Fuel flask.
9. Fuel access tube through containment.
10. Containment shell.
11. Fuel storage.
12. Fuel element building.
13. Air locks.
14. Turbine hall and control room.

THE Advanced Gas-cooled Reactor, or A.G.R., can be regarded as being midway between the H.T.G.C. previously described and the civil power stations now building, i.e., it aims at steam temperatures of around 850°F (454°C) as compared with the 1,110°F (650°C) of the H.T.G.C. reactor and the 700°F (371°C), which is about the highest of the commercial stations.

A reactor of 100 MW (heat) and 28 MW net electrical output is expected to be completed during 1961 at Windscale. The reactor is essentially a research unit and will be provided with two lines of 12 experimental channels disposed diametrically across the core. In addition, five channels in the centre of the reactor will allow loop experiments to be made on elements under extreme conditions. It appears that core blocks and elements can be removed together, and by taking off the reactor head the whole moderator can be changed.

An unusual design feature is the containment vessel which, with a conical lower portion, is more economical than the sphere or cylinder and gives easy access to the critical lower seam.

The graphite moderator is a cylinder of about 20 ft diameter (including reflector) and 15 ft active diameter, and contains 240 fuel channels. Each channel is provided with its own individual access pipe, so that each channel can be fully instrumented and fitted with its own flow control, and refuelling of a channel can be carried out on load with full gas pressure.

TABLE 1.—General Particulars of 100 MW (28 MWE) A.G.R.

Core length, active	14 ft
Core diameter, active	15 ft
No. of fuel channels	250
Gas pressure	270 p.s.i.
Inlet temperature	250°C–325°C
Outlet temperature	500°C–575°C
Can surface temperature	600°C
Total weight of UO_2 in core	14.6 tonnes
Mean rating	7.75 MW/t
Peak rating	18.0 MW/t
Initial enrichment	1.65 Co
Thermal flux average	1.49×10^{13} n/cm², sec
Thermal flux max.	3.45×10^{13} n/cm², sec
No. of control rods	25
Total reactivity absorbed	14%
Diameter of pressure vessel (int.)	21 ft
Overall height of pressure vessel	60 ft
Weight of moderator (inc. reflectors)	200 tons
No. of external circuits	4
Blower power	4×1200 h.p.
Steam conditions at superheater outlet	620–670 p.s.i., 860°F (460°C)
Dump condenser rating	100 MW

The fuel used is uranium oxide 95% theoretical density, and 1.2% enrichment, in the form of pellets approximately 0.3 in. dia. and 0.3 in. long, contained in a beryllium can of wall thickness 0.030 in., containing helium, the fuel rods so formed being assembled in groups or clusters, each containing some 30 rods. The final number has not yet been definitely established; for the most efficient "nesting" the ideal number would be 37, as in the core of a cable, but this might lead to a certain amount of self-shielding and the number will probably be smaller. In all, there will be some 13-15 of these clusters or a total of 400-450 rods in each channel. Up to half the experimental channels will be loaded with steel-canned fuel elements.

The reactor vessel is in mild steel, approximately 21 ft internal diameter and 60 ft high, with a detachable head. Double shell construction is used to allow of the pressure parts to be cooled by being swept with gas at inlet temperature (250°C to a maximum of 325°C). Alloy steel is used for the hot gas manifold at the top of the core, and for the ducts to the heat exchangers. The coolant is carbon dioxide at a pressure of 270 p.s.i. and an outlet temperature of 500-575°C. The four coolant circuits, each with a 1,200 h.p. blower, feed four heat exchangers which generate steam at 600 p.s.i., 850°F; capacity is 60,000 lb/h.

* "Advances in the Design of Gas-cooled Graphite Moderated Reactors." Paper No. 312, by R. V. Moore, H. Kronberger and L. Grainger.

"LENIN"—The Russian Ice-breaker *

THE icebreaker "Lenin," which was launched in December, 1957, utilizes nuclear propulsion in order to be able to operate for long periods without refuelling. By this means it not only overcomes the difficulty of transporting fuel to Arctic regions, but is no longer confined to a comparatively narrow coastal limit hitherto set by normal bunkering needs. Stated to have a power/weight ratio some 1½ times that of any previous icebreaker, she is turbo-electric propelled by three screws. General particulars of the ship are given in Table 1.

TABLE 1.—General Particulars of Vessel

Displacement	16,000 tons
Length	134 m (440 ft)
Beam	27.6 m (90.5 ft)
Draught	9.2 m (28 ft)
Freeboard amidships	16.1 m (52.5 ft)
Max. speed (clear water)	18 knots
Operating speed in ice 2.4 m (7 ft 10½ in.) thick	2 knots
H.P. at turbine reduction gear	44,000 h.p.
Specific capacity	2.75 h.p./ton
Weight of power plant (without shielding)	1,054 tons
Weight of shielding	1,963 tons
Steam flow	360 ton/h (906,400 lb/h)
Steam conditions 28 kg/cm² (398 p.s.i.)	310°C (590°F)

It was originally intended that the "Lenin" should have two reactors, but it was finally decided that three should be provided, any two of which should be capable of giving full output. These are arranged in line athwart the ship with the two heat exchangers to each unit disposed fore and aft of their respective reactors. The pressure vessels and the iron for the water/iron shielding were installed with the ship still in the yards and pontoons were provided under the stem and stern to simplify launching.

The reactors, each of 90 MW thermal capacity, are of the pressurized light water type. A cross section of the pressure vessel and core is shown in Fig. 1, and general particulars are given in Table 2.

Several designs of core and fuel channel have been considered, and it is understood that the final choice of fuel channel will be made on the basis of convenience and economy after undergoing operation tests. The core described and exhibited at Geneva, however, consisted of fuel channels of stainless steel, approximately 5.5 cm (2.16 in.) diameter and 3 m (9 ft 10 in.) overall length, each channel containing 36 full rods consisting of sintered pellets of uranium oxide, sheathed in zirconium. The core is surrounded by a series of concentric steel shields giving a total

TABLE 2.—Reactor Particulars

No. of reactors	3
Thermal capacity of each reactor	90 MW
Core diameter approx.	1 m (39.3 in.)
Overall length of fuel channel	approx. 3 m (9 ft 10 in.)
Active length of channel	approx. 1.6 m (5 ft 3 in.)
Diameter of channel	5.5 cm (2.16 in.)
No. of fuel rods per channel	36
Total thickness of internal radial shielding	225 mm (8.85 in.)
Enrichment	5%
Total U^{235} loading for each reactor	85 kg
No. of regulating rods	6

* "Atomic Icebreaker 'Lenin'." By A. P. Alexandrov, I. I. Afrikantov, A. I. Brandaus, G. A. Gladkov, B. V. Gnesin, V. I. Neganov, N. S. Khlopkin.

Dessins de Réacteurs

Parmi les nombreux nouveaux réacteurs décrits à Genève, les dessins britanniques qui sont peut-être les plus intéressants sont ceux qui visent une augmentation de rendement des réacteurs refroidis au gaz.

Deux suites d'idées sont en train d'être étudiées. Dans la première la HTGC envisage des températures de gaz d'environ 650°C, en employant comme combustible un mélange fissile/fertile, c'est-à-dire un compact d'oxyde d'uranium-graphite. L'essai d'énergie zéro dans lequel la température nécessaire est obtenue par le chauffage électrique est en construction et on a mis à l'étude une installation pilote de 10 MW. Les possibilités comprennent aussi l'emploi d'un turbo-compresseur à fonctionnement libre pour agir comme circulateur actionné par lui-même dans le circuit de gaz.

L'AGR, ou réacteur avancé refroidi au gaz, envisage des températures d'environ 500–575°C, c'est-à-dire à mi-chemin entre le HTGC et les centrales commerciales. Une installation de 28 MW est en construction, et elle emploiera du combustible à l'oxyde avec du canning au béryllium.

Un autre dessin intéressant est celui du PWR russe dont le brise-glaces "Lénine" en aura trois, deux desquels, quels qu'ils soient, seront en mesure de fournir une puissance de propulsion de 44.000 CV.

Finalement, le réacteur de recherches BR2 belge semble posséder plusieurs caractéristiques très intéressantes y compris une disposition inclinée des canalisations du noyau et l'emploi de béryllium comme modérateur.

Reaktor Entwürfe

Unter den vielen neuen Reaktoren, die in Genf besprochen sind, sind möglicherweise die interessantesten englischen Entwürfe diejenigen, die auf grössere Leistung bei gasgekühlten Reaktoren hinzielen.

Zwei Gedankengänge werden verfolgt. Der HTGC zielt auf Gastemperaturen von rd. 650°C bei Benutzung einer spaltbaren/brutfähigen Brennstoffmischung, d.h. eines Graphit-Uranoxyd Kompakts. Die Null-Leistungs Forschungs-Apparatur, in der die notwendige Temperatur durch elektrische Beheizung erzielt wird, ist unter Konstruktion, und man studiert die Möglichkeiten einer 10 MW Versuchsanlage. Die Möglichkeiten schliessen weiter die Verwendung eines unabhängig laufenden Turbokompressors ein, der als mit eigener Kraft versehene Umlaufspumpe den Gasumlauf bewirken soll.

Der AGR, der fortgeschrittene gasgekühlte Reaktor, hat das Ziel, Temperaturen von rd. 500–575°C zu erreichen, d.h. in der Mitte zwischen HTGC und den kommerziellen Werken. Ein 28 MW Werk ist im Bau und wird als Brennstoff Oxyd in Beryllium-Hülse benutzen.

Ein weiterer interessanter Entwurf ist der russische PWR, wovon der Eisbrecher "Lenin" drei Stück haben soll, von denen immer je zwei im Stande sein sollen 44.000 PS als Antriebsleistung aufzubringen.

Schliesslich scheint der belgische BR2 Forschungsreaktor mehrere sehr interessante Punkte aufzuweisen, u.a. eine schräge Anordnung der Kernkanäle und die Verwendung von Beryllium als Moderator.

Diseños de Reactores

Entre los muchos reactores nuevos descritos en Ginebra, es posible que los diseños británicos más interesantes resulten aquellos enfilados a aumentar la capacidad de los reactores enfriados a gas.

Se siguen aquí dos líneas distintas. En la primera el HTGC tiende a lograr temperaturas de gas alrededor de 650°C, utilizando una mezcla fisible/fertil como combustible, es decir, una composición de grafito-óxido de uranio. El experimento de energía cero en el cual se logra la temperatura necesaria se logra calentando eléctricamente la parte inferior de la construcción y se viene haciendo un estudio de una planta piloto de 10 MW. Entre las posibilidades figura también el empleo de un turbo-compresor equilibrado que actúe como circulador automandado en el circuito de gas.

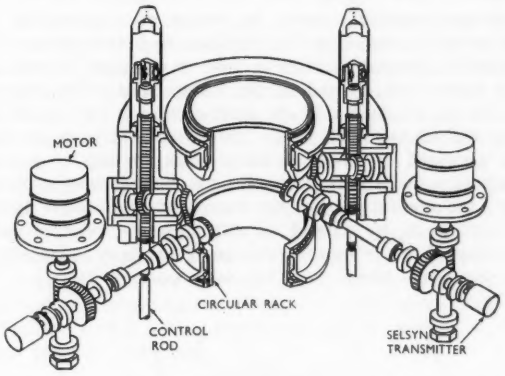
El AGR, o reactor avanzado enfriado a gas, tiende a lograr temperaturas de alrededor 500–575°C, es decir, a medio camino entre la HTGC y las estaciones comerciales. Una planta de 28 MW está en construcción y empleará óxido de combustible con encierre de berilio.

Otro diseño interesante es el ruso PWR del cual el rompehielos "Lenin" llevará tres, y cualquiera de dos son capaces de suministrar energía de propulsión a razón de 44000 HP.

Finalmente, el reactor de investigación belga BR2 parece presentar varios puntos interesantes incluyendo una disposición inclinada de los canales del núcleo y el empleo de berilio como moderador.

radial thickness of 225 mm (8.85 in.) of steel and water passages.

Coolant flow through the reactor is as generally indicated in Fig. 1, water entering at the bottom of the reactor. The bottom plate of the core, which holds the fuel channels has



(Left) Fig. 2.—Automatic control mechanism.

baffles blanking off the two outer circles of channels from the main coolant flow, so that the major portion of the water passes through the central channel region, while a small portion of it is diverted downwards through the shields and upwards through the outer channels, which have a smaller heat release.

Control

For power level and transient control there are six control rods, arranged for independent operation as two sets of three rods. Normally, only one set is in operation, the other set being kept as a standby, or occasionally used for trimming purposes, in the same way as a manual control rod.

Fig. 2 indicates the general operating principles of the control mechanism, automatically operated from the main control panel. For simplicity, the diagram shows only one rod of each of the two groups; the three rods of each group are all driven from the same circular rack mechanism.

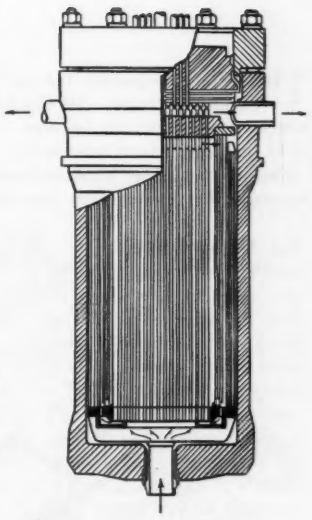
In addition, there is a system of compensating plates to take care of the slow changes in reactivity due to poisoning, and burn-up. These are raised or lowered by a single rod, with a screw thread and ball nut mechanism motor-driven through reduction gearing.

Finally, there are a number of safety rods which are raised by motor-driven racks against powerful springs. Magnetic clutches are used between the motor and the rack, so that rapid release is possible, and it is stated that scramming can be carried out in 0.6 sec.

Steam Plant

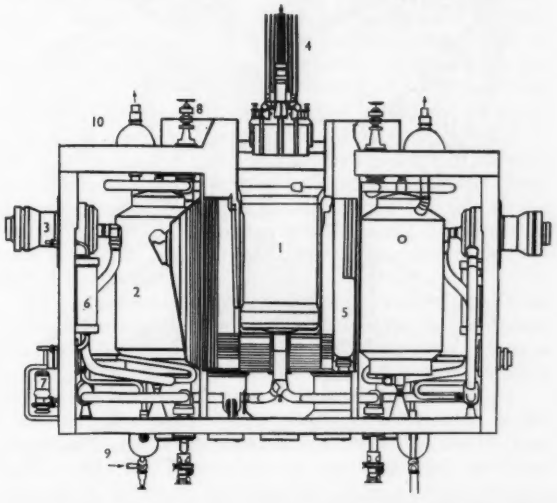
There are, in effect, three separate steam plants, each associated with one reactor. Each unit, as shown in Fig. 3 consists of reactor, two steam generators, circulating pumps and "volume compensators" or pressurizers, in addition to auxiliaries such as cooler and filter units. The main circulation pumps for each circuit are duplicated, the two motors being fed from different supplies; there is also an emergency pump in each circuit. The capacity of each main pump is 500 m³/h (1,840 gal/min), and both main and emergency pumps are of the canned-rotor type, with hydrostatic bearings for the main pumps and plastic bearings for the emergency pump. The pressurizers are electrically heated, the heating being controlled to maintain constant circuit pressure.

(Right) Fig. 1.—Arrangement of reactor, showing water circulation.



(Below) Fig. 3.—General layout of complete unit.

1, Reactor; 2, Steam generator; 3, Main circulating pump; 4, Control rod mechanism; 5, Filter; 6, Cooler; 7, Secondary circuit pump; 8, Primary steam valve; 9, Feedwater inlet. 10, Steam outlet.



To minimize contamination of the reactor filters are provided in a by-pass circuit. Coolers provide purified water for cooling the pumps.

There are two auxiliary cooling circuits for each unit. One, the "interior" circuit cools the shield, while the "exterior" circuit, which provides secondary cooling for the interior circuit, as well as for filters, etc., is itself cooled by sea-water.

The heat exchangers themselves consist of cylindrical shells, with an internal uniflow tube system, divided into economizer, boiler, and superheater zones, the total heat transfer surface of each steam generator being 375 m² (4,035 ft²).

In operation, the reactor output level is set by the control rods and the primary coolant circulation is kept at a constant figure; transient variations in demand being dealt with by feed water regulation.

Secondary steam generators are provided, operated from the main steam, to supply auxiliary steam for bathrooms, laundries and general ship's use, to avoid any possible spread of radioactive contamination in case of failure of a fuel element in the reactor.

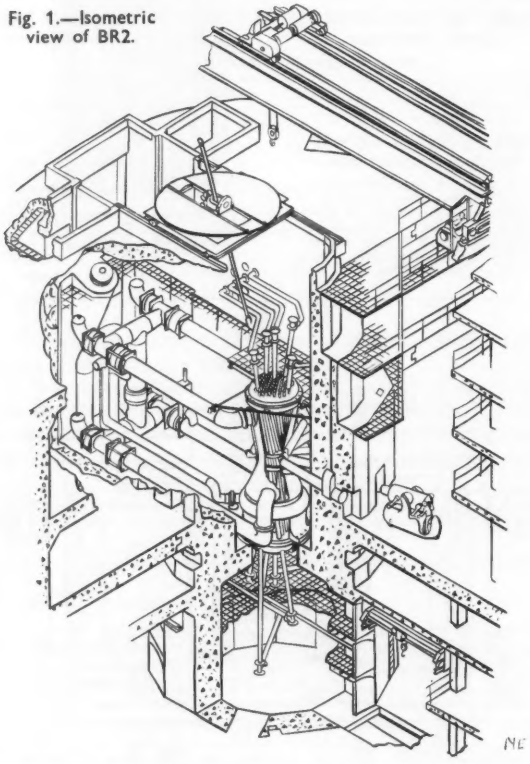
The entire primary circuit plant for each unit is surrounded by steel containment varying from 300-420 mm (approximately 12-16½ in.) thick.

The Belgian BR2

THE Belgian materials testing reactor BR2 at the C.E.N. (Centre d'Etude de l'Energie Nucléaire), Brussels, which is expected to become critical about the end of 1959, presents many interesting features.

Designed by the Nuclear Development Corporation of America the reactor uses beryllium moderation and light water cooling, possessing in effect characteristic features of both tank and pool type reactors.

Fig. 1.—Isometric view of BR2.



Probably the most interesting feature of the BR2 is the skewed arrangement of the core, which consists of a number of circular channels for either fuel or experimental facilities, which pass through the moderator; a matrix of beryllium. Instead of being arranged vertically, however, the channels are skewed or inclined not more than 11° from the vertical, thus forming a "waisted" or "diabolo-shaped" arrangement. The main advantages of this arrangement are, of course, that a compact core can be obtained, while allowing ample clearance between the ends of the channels for properly-designed plugs and sealing arrangements.

The general arrangement of the reactor is shown in Fig. 1, while Fig. 2 shows a cross-section of the core at its mid-point.

The core is 110.04 cm (43.324 in.) in diameter, and 91.44 cm (36 in.) long, made up of irregular polygonal bars of beryllium, shaped to nest into the tubes, but not touching, so as to allow passage for the coolant.

Each fuel element is an assembly of six concentric tubes ranging from 3.3-7.62 cm (1.3-3 in.) diameter, with an active length of 76.2 cm (30 in.). The tube wall has the same section as the MTR fuel plate, with 0.5 mm "meat" in the form of 90% enriched uranium-aluminium alloy clad with 0.13 mm thick aluminium. Each element contains about 250 g of U^{235}.

The pressure vessel has a cylindrical mid-section and truncated cone end sections, all in aluminium, the domed ends being stainless steel. By means of a support skirt, the vessel is sealed to the bottom of a swimming pool enclosure, passing through a hole in the pool bottom so that access can be had to the lower head. The pool is 15.5 m (51 ft) deep, and the main section is 14.9 m (49 ft) long and 4.9 m (16 ft) wide. Two shallower wing sections are provided to house a core mock-up and a gamma irradiation facility respectively, the wings being isolated from the central section by watertight aluminium doors.

Cooling is by closed circuit through external heat exchangers, this primary circuit being normally independent of the pool which has its own cooling system. In emergency, the primary coolant can be circulated at a reduced rate by an emergency pump, can transfer heat to the pool by natural convection through a submerged heat exchanger, or can be connected directly to the pool to maintain water level.

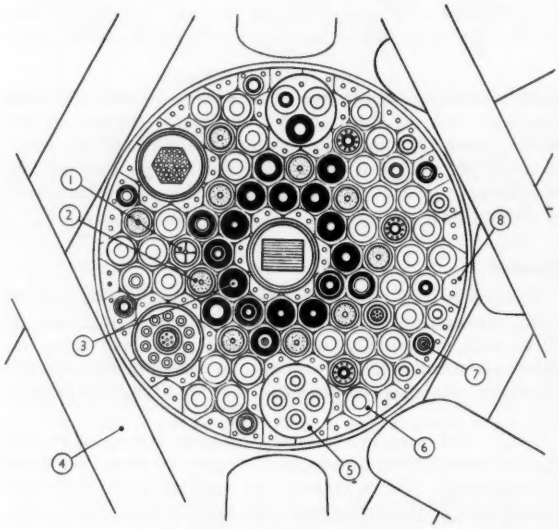


Fig. 2.— Cross section of core.
1, Regulating rod; 2, Shim-safety rod; 3, Fuel element; 4, Beam hole; 5, Large through hole; 6, Beryllium plug; 7, Rabbit; 8, Beryllium matrix bar.

TABLE 1.—BR2. General Particulars

Power	50 MW
Fast flux n/cm², sec, max	2.4×10^{15}
Fast flux n/cm², sec, average	1.0×10^{15}
Thermal flux n/cm², sec, max	6.2×10^{14}
Thermal flux n/cm², sec, average	4.6×10^{14}
U^{235} critical mass	4 kg
Temperature coefficient, per °F	-5×10^{-5}
Beryllium matrix length	91.44 cm (36 in.)
Beryllium matrix dia.	110.04 cm (43.324 in.)
Inside diameter of channels	5 of 20.32 cm (8 in.)
	64 of 8.42 cm (3.315 in.)
	10 of 5.01 cm (1.971 in.)
Standard channel length from support grid to top seal plug	672.6 cm (22 ft 0.8 in.)
Pressure vessel	
Operating pressure	12.7 kg/cm² (180 p.s.i.)
Operating temperature	47°C (117°F)
Length over flanges	750.6 cm (24 ft 7½ in.)
Diameter at core midplane	110.72 cm (43¹⁹/₃₂ in.)
Main coolant system	
Total flow	1,760 l/sec (27,900 gal/min)
Inlet temperature	40.6°C (105°F)
Outlet temperature	47.2°C (117°F)
Pumps (3 operating, 1 standby), each	740 h.p.

"BR2—The Belgian Materials and Engineering Test Reactor." Paper No. 1679, by H. Dopchie and J. Planquart.

Report from Geneva—5

A Survey of Water Reactors

A HIGH proportion of the papers on power reactors concerned either pressurized water or boiling water reactors. The former have become established in the United States and there is Russian experience of them. For marine propulsion, the papers indicate that they have been a first choice in several merchant ship studies. The greatest change since the 1955 Conference, however, is the increase of interest in boiling water power reactors. A number of U.S. and U.S.S.R. papers are devoted to the system and its variants, and the presentation of the U.S. papers in particular showed much enthusiasm for them.

The papers covered a wide field from descriptions of proposed and operating water reactors to the details of their technology, and it is only possible to give an outline of the major projects described.

Pressurized Water Reactors in the U.S.A.

The pressurized light water reactor was the first power system to be developed for significant outputs in the U.S.A. It has its roots in the system developed for submarine propulsion and shown to be so successful for the "Nautilus." This application, being outside the scope of the Conference, was not referred to in any detail, but the land-based prototype S.1.W., first operated in May, 1953 at the National Reactor Testing Station in Idaho, was the starting-point of the type of electricity generating reactor now operating at Shippingport (1075).

The "Nautilus" S2W system was in operation early in 1955, and was immediately followed by the start of the construction of the Shippingport PWR, and the Army Package Power Reactor, APPR 1; the former operated at full power in December, 1957, and the latter in April, 1957. It was emphasized during the Conference that the Shippingport reactor is primarily an experiment in large-scale PWR technology, and that it would be unwise to draw from it conclusions on the economic potential of the type.

Disadvantages of the PWR system for large central stations are the low temperature and pressure at which steam is produced, leading to relatively low efficiency and large and expensive steam plant (1076). One has become accustomed to the diversity of outlook on reactor systems in the U.S., but it is surprising to find that in two large PWR stations, Yankee and Indian Point, the first is a development of the Shippingport plant with the disadvantages just mentioned, while the second employs oil-fired superheating to overcome them.

The Yankee plant (1038), now under construction and due to operate in 1960 with an electrical output of 134 MW, follows Shippingport practice in general except that the fuel is uranium oxide pellets of enrichment 3.1% clad in stainless steel tubing. At a capital cost of $50 M it is stated that with a load factor of 80%, electricity will eventually be produced at 12-14 mills per kWh with an expected overall thermal efficiency of 27%. A prime consideration in this design appears to have been the development of the Shippingport system to a more commercial plant.

Indian Point (1885), with oil-fired superheating is due to operate at full power in January, 1961. An interesting development is the admixture of highly enriched (+90%) UO_2 with thoria in the ratio 1 : 29 for the fuel, thus providing for U^{233} to extend the fission life of the fuel. Of the total 275 MW output, 163 MW will be supplied by nuclear fuel and the remainder by oil; the overall thermal efficiency is estimated as 32% and, at 80% load factor, the cost per kWh of electricity as 13.2 mills.

The economic position of this plant is described in the paper. If it were built without a superheater it would cost $77 M and yield 163 MW of gross capacity at a capital cost of $472 per kW. The addition of the superheater and ancillary plant increases the total cost to $90 M and the gross capacity to 275 MW at $327 per kW. These prices were compared with $225 per kW for new high-pressure reheat steam units in New York City. For the nuclear plant alone, producing saturated steam at 80% load factor, the unit cost is estimated at 17.5 mills/kWh; with the addition of oil-fired superheating this figure is reduced to 13.2 mills/kWh. These figures are compared with 8 mills per kWh for modern stations in New York City based on a coal cost of $10/ton.

The authors state that if coal (and oil equivalent) were to be $20 per ton as in Europe, production costs per kWh for a modern conventional station would be 11.8 mills which is not much below the 13.2 mills quoted for the Indian Point plant. The breakdown of costs makes interesting comparison with the Yankee plant, but despite the case put forward for the addition of oil-fired superheating, there was some sympathy at the Conference with the purist view that all the energy should be supplied by nuclear means if it could be made economic, especially for oil-importing nations like the United Kingdom.

The first pressurized water reactor to be exported from the U.S. is described in paper 416. This is the Belgian plant BR-3 which is being supplied by Westinghouse. It is a straight PWR of 43 MW thermal and 11.5 MW capacity and is expected to go critical in December, 1959.

The full-size model of the Shippingport reactor in the American section of the exhibition at the Palais des Nations was a sobering illustration of the technical problems involved in this route to large-scale nuclear power. Nevertheless, the type is being pursued vigorously and appears to be the choice for several ship projects. The Russians have installed it in the "Lenin" and the Americans have chosen it for their first merchant ship—the "Savannah." The U.S. is also studying the advantages to be obtained by substituting heavy for light water in pressurized water power reactors, particularly the use of natural uranium as fuel. Two projects are under study (2447 and 610).

In each U.S. land-based power plant there is only one reactor and all reactors are contained, the cost of containment being one of the dominant factors in their economics.

U.S.S.R. Pressurized Water and Boiling Water Reactors

Experience in operating the first Russian power reactor, graphite moderated and water cooled, is described in paper 2183. This reactor was first described at the 1955 Conference. It was built as an experiment with an output of 5 MWE and 5% fuel enrichment. Since the last conference, certain reactor channels have been cooled under both boiling and steam superheating conditions and the results have been encouraging enough to prompt the building of the system in larger sizes.

The PWR system is under study in the U.S.S.R. for both land (2184) and marine use (2140). One of the most interesting applications is the icebreaker "Lenin" (2140) which has three reactors each of 90 MW thermal output. Under

normal conditions two reactors are working with the third as stand-by. It is expected that the ship will be operating in the spring of 1959.

The point was made by Russian authors that, with their method of encasing the enriched fuel elements of the graphite moderated types in stainless steel tubes, a long irradiation life was to be expected in the fuel, thus permitting a good economy.

A number of projected reactors of the graphite moderated, water and steam cooled type were described, in particular a 100 MWE electrical station in which the steam produced in boiling channels is separated and returned to superheating channels in the reactor.

Pressurized Heavy Water Reactor in Canada

The Canadian power programme is based on natural uranium in the form of oxide and heavy water as moderator and coolant. As a first, largely experimental, step, NPD-2 reactor is being built (209) for completion in 1961. The designed power is 20 MWE and the coolant pressure 1,000 p.s.i. This plant is intended as a pilot for units up to 300 MWE output.

An interesting feature, as in some of the Russian reactors, is the use of pressure tubes rather than pressure-shell construction. The decision to adopt this was taken in 1957 when the NRD-1 design was superseded, and is due to the large reactor diameters necessary with heavy water moderation, as compared with light water, for the larger powers. It seems clear that power reactors cooled by water and steam will have pressure shells only when moderated by light water and not when moderated by graphite or heavy water.

European Heavy Water Reactors for Power and Heating

A number of papers referred to projects with relatively small output, where the economy could be improved by using heat for district or process heating either with or without a power plant.

Two Swedish papers are concerned with plans for district heating by way of natural uranium heavy water moderated and cooled reactors. Paper 136 describes a 75 MW thermal plant (ADAM) with uranium oxide as fuel. The heavy water is intended to leave the reactor at 140° C and to heat the circulating water in a heat exchanger. The completion date aimed at is 1961. The second proposal (135) is for a pressurized heavy water reactor (R-3) designed to combine electricity production with district heating.

In Switzerland, a 30 MW thermal heavy water moderated and cooled pressure-tube system, with slightly enriched fuel, has been planned by the Sulzer Co. for construction in Zürich to give both power and district heating (246). The project is experimental and, like the Swedish ADAM, is to be built underground.

A courageous proposal for a boiling heavy water reactor in Norway was described at the 1955 Conference, and its progress is given in paper 559 of this Conference. It is of the dual cycle type, of 10 MW heat output and is experimental in character, being regarded as a plant in which to study the physics and engineering problems of the type. Although the power circuit will contain light water and steam heated via a heat exchanger by the heavy steam, consumption of heavy water will be one of the many interesting figures to be found. Operation should be possible with only slight enrichment of the fuel, and is planned to begin experimentally at the end of 1958.

Boiling Water Reactors in the U.S.

There is a good deal of enthusiasm in the United States at the present time for boiling light water power reactors. Under a less diverse programme one would expect the BWR to emerge from the development of the PWR towards boiling conditions, but, in fact, the BWR has been studied in its own right since 1953 when the Argonne National Laboratory built BORAX 1 to find out if boiling caused power instability. The results were encouraging and a second reactor, EBWR, was built to operate in 1956 at 5 MWE. To date, three more Borax experiments have been conducted to gain information from transient tests, on the effects of heat release per unit volume and on the likely contamination of power turbines with radioactivity. Paper 2379 contains some of the significant results of the operation of BORAX IV and EBWR, both of which are direct-cycle, natural-circulation reactors.

In addition to these AEC experiments, General Electric built a 5 MWE BWR at Vallecitos (1923) which has operated since mid-1957. As a result of this very considerable small-scale experience, G.E. has undertaken the construction of a 180 MWE dual cycle BWR for the Commonwealth Edison Co. at Dresden, near Chicago (2372), to be completed by mid-1960. The fuel is of relatively low enrichment (1.5%) in ½-in.-diameter uranium oxide pellets clad in Zircaloy[2]. The purchase price quoted is $45 M, one third of which is for research and development.

It is stated that, based on the capital sum of $30 M, the cost of a unit of electricity will be about 7.5 mills; about the same as that for Commonwealth Edison's newest coal-fired plant. However, this capital sum does not represent the real cost of the BWR plant; the costs incurred by General Electric exceed $45 M and the power output would not be competitive if all expenditure, including development costs, were taken into account (2447). Although the plant efficiency is quoted as 28.7%, the primary and secondary steam produced (965 p.s.i. and 475 p.s.i.) is saturated and moisture-separating devices are essential in the turbine.

The operations results of this first full-scale BWR will be awaited with keen interest, especially on the question of nuclear and hydraulic stability, which have so far been studied only in laboratory experiments and much smaller reactors.

From the design experience with the Dresden plant G.E. has completed a design study (2372) of a 200 MWE Advanced BWR in which cost reductions are sought by such simplifications as a single cycle in place of the dual cycle, and the elimination of steam generators. Despite the recognition of the desirability of nuclear superheat it is apparently not intended to adopt it in this new design.

Although experience so far shows that direct cycle BWRs with uranium oxide or alloy fuels have not given rise to excessive radioactivity in the steam circuit, this point is receiving a good deal of attention such as the deliberate insertion of defective fuel elements in BORAX IV (2379). Clean-up measures include by-pass ion exchange loops. It appears that the fission product radioactivity problem in the steam must be dealt with entirely by fuel element integrity; the location of a fault within the reactor becomes a long and tedious operation.

One cause of radioactive steam contamination has been found to be the pressure, in the steam, of erosion products such as cobalt, arising from steam leakage paths in turbines. Where it is not possible to eliminate these paths, the surfaces are being covered with erosion-resistant deposits.

The possible troubles with steam circuit radioactivity are avoided in a projected 125 MWE indirect cycle BWR intended for Belgium in the near future (1801). It is a joint project of Belgo Nucléaire and the General Nuclear Engineering Corporation of the United States. The power steam circuit receives heat from the primary circuit through heat

Report from Geneva—6

Fast Reactors

SOME details of five fast reactors built or under development in the U.S.S.R. were given in paper 2129 by Leipunsky *et al.* BP-1, completed in 1955, is an uncooled zero energy assembly, fuelled with plutonium rods in stainless steel cans. It appears to be similar in general form and purpose to ZEPHYR and control is achieved by moving parts of the reflector. BP-2 is a 100 kW plutonium fuelled reactor for nuclear and materials testing at fast neutron fluxes up to 10^{14} n/cm², sec. Its form, fuel elements and method of control are similar to BP-1, but mercury is used as coolant, the choice being dictated by lack of experience with sodium.

BP-5 was described as a 5 MW reactor fuelled with plutonium oxide, with a core consisting of 1,520 elements of 0.5 cm diameter, arranged in 80 sub-assemblies. On account of blanket cooling difficulties, a nickel reflector is used rather than a uranium blanket, there being an internal uranium reflector at the centre of the core. As in the other reactors, control is achieved by reflector movement. The primary coolant is sodium, heat being transferred to a NaK secondary circuit and thence to air or steam. Tables are presented giving basic thermal and neutronic data. The dry reactor diverged early this summer, and is now operating at zero power. It is to be filled with sodium shortly. The pumps for BP-5 are described as being mechanical, fitted with flywheels which maintain circulation for about one minute in the event of a power failure.

It is difficult to judge from the U.S.S.R. papers what importance is attached to the development of fast reactors. Basic parameters were given for a projected 50 MW(E) and 250 MW(E) power station using sodium-cooled plutonium oxide fast reactors, but it is not clear how far, or how seriously, work has proceeded.

Comparison of U.S. and British Designs

Papers on the engineering design of the two medium-power fast reactors, the American EBR-II (1782) and the British Dounreay Fast Reactor (274) enable a comparison to be made between radically different solutions of the same problem. The EBR-II core is described in considerable detail, and its design has undergone many modifications since 1955. The core, primary circulating pumps and primary heat exchanger are all contained in a large tank of sodium with access from the top. The designers finally appear to favour the use of two single-stage centrifugal pumps in parallel having large sodium bearings located at the impellers. Auxiliary d.c. magnetic pumps of a rugged design are included in series with the main pumps. The d.c. pumps utilize a permanent magnet and are energized by a rectifier, across which also floats a NiFe storage cell. They are capable of providing 5%-8% of full load flow for up to two hours and assist in smooth transition to natural convection flow.

Some of the predicted effects of primary pump failure are described (458) in addition to other aspects of the dynamic behaviour of EBR-II. Although the use of an auxiliary magnetic pump is an added design complication, it does provide for the contingency of a mechanical failure in the

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WATER REACTORS (*Continued from opposite page*)

exchangers and a high efficiency (37%) is planned, using oil- or coal-fired superheating. The expected power cost is about 10 mills per kWh. Three further BWR stations are planned by various U.S. companies.

The BWR is also to have its packaged version to match the APPR. Paper 455 describes a direct-cycle, natural circulation BWR for power production (300 kW) and space heating (400 kW) for remote locations.

The stage at which water reactors for power have arrived underlines the unpredictable course which nuclear energy has followed in its first decade. Ten years ago the PWR was conceived as a unit small enough to propel a submarine where economics were of secondary importance. By direct development it has grown to the Shippingport, Yankee and Indian Point plants although, even with separately fired superheating, it is not yet competitive with coal. The fear of instability due to boiling which has led to considerable overpressures in the PWR type prompted the Borax I experiment to check the point. From there boiling water reactors have grown to full-scale projects, which, since they operate at lower pressures and are basically simpler, in the direct-cycle version at least, appear to have a greater potential than the PWR. It remains to be seen from experience how economic and safe they can be made to be.

The economics of light water reactors, which require enriched fuel, hinges upon the very uncertain cost of this fuel. It seems that the American types can approach a competitive electrical unit price only if the enrichment plants use electricity produced by non-nuclear means such as water power or the relatively low priced American coal.

So far as countries like the United Kingdom are concerned, the ultimate system would be one which is economically self-propagating without the necessity to rely on water and coal to make nuclear plants competitive.

(*Translations on page* 465)

PAPERS LISTED

135 Margen, P. H., *et al.*; R3—a natural uranium fuel heavy-water moderated reactor for combined electricity production and heating.
136 Wivstad, I., *et al.*; ADAM—A 75 MW Nuclear Energy Plant for House Heating Purposes.
209 MacKay, I. N.; The Canadian NPD2 nuclear power station.
246 de Haller, P., *et al.*; Sulzer project for a prototype heavy-water power reactor for location in an underground cavern.
416 Del Campo, A. R., *et al.*; Belgian Thermal Reactor (BR-3).
455 (U.S.) Design and initial performance of a direct cycle boiling reactor package plant for electrical power and space heat.
559 Hidle, N., and Dahl, O.; The Halden boiling heavy-water reactor.
610 Babcock, D. F.; Heavy-water moderated and cooled power reactors.
1038 Voysey, A. E., *et al.*; The Yankee Plant.
1075 Goodman, C., *et al.*; Experience with U.S. Nuclear Power Reactors.
1076 Davis, W. K., *et al.*; Highlights of nuclear power in the U.S.
1801 Zinn, W. H., *et al.*; A 125 MW indirect cycle boiling-water power reactor.
1885 Milne, G. R., *et al.*; The Consolidated Edison Co. of New York nuclear electric generating station.
1923 Beckjord, E., *et al.*; Operation of a high-performance light water boiling reactor.
2140 Khlopkin, N. S.; The Nuclear-Propelled Icebreaker.
2183 Krasin, A. K., *et al.*; Operating the first atomic power station in the U.S.S.R., and its work under boiling conditions.
2184 Skvortsov, S. A., *et al.*; Pressure water reactors in the U.S.S.R.
2372 Elliott, V. A.; The Dresden nuclear power station.
2379 Harrer, J. M., *et al.*; Performance evaluation of direct cycle boiling water nuclear power plants based on recent EBWR and BORAX data.
2447 Hilberry, N.; Report on Full Scale Power Reactor Projects in the United States of America.
2462 Simpson, J. W., and Rickover, H. G.; Shippingport atomic power station.

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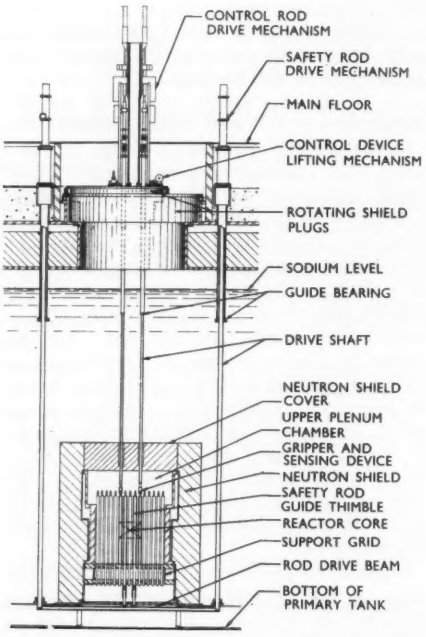
main pump (e.g. liquid metal bearing seizure) in which event a flywheel would be of little use. In addition much more energy can be stored. Some details of the design and performance of the pressurized bearing mechanical pumps are given in paper 2158.



Control rod drive system for EBR-II (Paper 1782).

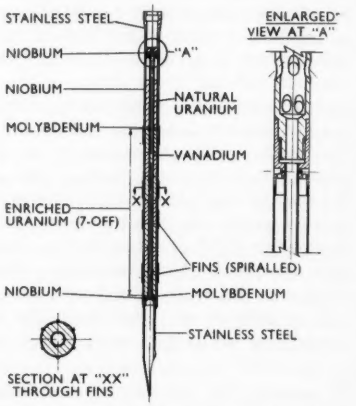
Unlike EBR-II, the coolant flow in the Dounreay reactor is downwards in the core, the designers' view being that the disadvantages from the point of view of natural circulation in the event of all pumps failing were outweighed by the other mechanical and safety advantages. At Dounreay the primary pumps and heat exchangers are outside the reactor vessel, the designers having favoured a large number of completely independent heat transfer circuits, each with its own pumps, on the basis that failure of one pump or heat exchanger will not seriously impair reactor operation. The EBR-II relies on one primary heat exchanger which should be relatively easy to replace; an approach which is made possible by the use of two shut-down coolers, and by the large thermal inertia of the system.

The fuel elements of the two reactors differ radically. The EBR-II element consists of sub-assemblies of small pins with stainless steel canning which are favoured in the U.S., whereas the Dounreay reactor has individual annular fuel elements with spiral fins; the inner and outer cans being of different materials in order that the inner tube should fail first during a melt-out.

Control of both reactors is achieved by moving fuel. If access to the vessels is restricted to the top, the problem of the control rod drives is a difficult one. The simplest method is to drive the rods directly into the core from the top of the vessel. This has the disadvantages that the controls cannot be used during loading and unloading operations. The Dounreay reactor circumvents this by using a fairly complicated drive, which passes outside the core and moves the control rods from the bottom. EBR-II retains the simple direct drive for normal control rods, and employs two separate rods, with a more complex cranked arrangement for control during loading and unloading.

Some details are given of the integrated fuel processing cycle in the EBR plant. Briefly it is proposed to cool elements for 15 days and melt them in 10 kg batches in an oxygen deficient environment, thereby releasing the noble gas and volatile fission products. The stable rare earth oxides will appear in the slag. Some of the more noble and refractory metals will remain in the fuel when it is returned to the reactor, and it is proposed to incorporate predetermined amounts of these in the fuel in order that equilibrium conditions shall be attained rapidly. The 15-day cooling period in the reactor tanks will permit gas cooling of the elements during transfer to the process plant.

Paper 2427 contains an extensive and well-illustrated appraisal of the 100 MW(E) Enrico Fermi fast reactor which is at present under construction near Detroit, Michigan. The reactor is fuelled by 485 kg of U^{235} at 28% enriched uranium. Unlike the EBR-II scheme, aqueous processing is proposed—although it is pointed out that, in these circumstances, the out-of-pile inventory is equal to the in-pile inventory. It shares many design features with EBR-II.



Details of Dounreay fuel element (Paper 274).

The core is contained in a large tank of sodium which also houses fuel storage equipment, though not, as in EBR-II, the primary pumps and heat exchangers. Primary and secondary coolants are sodium and flow is upwards through the core, discharging directly into the reactor vessel. Both the coolants are circulated by centrifugal sump-type pumps having inert gas seals, there being three pumps in the primary and three in the secondary circuits. With any one pump shut down, 85% of full power can be maintained, and presumably for this reason the auxiliary pumps provided in EBR-II were not considered necessary. Unlike the other reactors boron-10 is used for control. From the description given it does not appear possible to change control rod position while fuel is being loaded or unloaded.

A potential weakness in all designs is the use in critical places of sliding parts in a sodium environment.

The potential hazards associated with fast reactors form the basis of several papers. By far the most difficult one to assess is that resulting from core melt-down. Some of the problems which arise in assessing the possible results of a melt-down are dealt with in paper 2165. It is fairly clear

PAPERS LISTED

274 Cartwright, H., *et al.*; The Dounreay Fast Reactor—Basic Problems in Design.
458 Bump, T. R., *et al.*; Predicted Dynamic Behaviour of EBR-II.
1782 Koch, L. J., *et al.*; Construction Design of EBR-II: an Integrated Unmoderated Nuclear Power Plant.
2129 Leipunsky, A. E.; Experimental Fast Reactors.
2156 Brittan, R. O.; Analysis of the EBR-I Core Melt-Down.
2158 U.S.A.; Characteristics and Performance of a 5,000-gal/min A.C. Linear Induction and Mechanical Centrifugal Sodium Pumps.
2165 McCarthy, W. J., *et al.*; Studies of Nuclear Accidents in Fast Power Reactors.
2427 Amorosi, A., *et al.*; An Appraisal of the Enrico Fermi Reactor.

that the rate at which a supercritical fuel mass can occur during melt-down depends upon complicated hydrodynamic factors and hence upon the coolant conditions during the process. It is not so obvious that a critical fracture can be the exact mechanism causing fuel can failure, and this may arise from complex fast high-temperature metallurgical processes, the reaction rates for which are imperfectly known. The only published case of a fast reactor melt-down is that of EBR-I and is dealt with in paper 2156.

(*Translations on page* 442)

Report from Geneva—7

Liquid Metal Technology

IN general three stages are involved in the development of a liquid metal technology to the state where it can be used in a reactor:—

(1) Metallurgical studies aimed at specifying container materials temperature limitations and amounts of allowable impurities.

(2) Development of engineering scale circuitry. This includes fabrication techniques, purification equipment, filling and emptying methods, and involves valves, pump indicators, meters and simple heat exchangers.

(3) Design of reliable and economical reactor components. Much more is involved here than a simple scaling-up of equipment developed in (2). The main burden falls on the designer, who must be given adequate information through his theoretical and experimental aides.

A powerful reason for embarking on the development of sodium reactor technology was that preliminary work indicated that Stage 1 would prove soluble in terms of fairly simple engineering materials. Although the degree of purity required has turned out to be higher than anticipated and although some unexpected mass transfer effects have been encountered, Stage 1 had, by and large, been passed satisfactorily at the time of the last Geneva Conference. Consequently few papers deal with this subject. Stage 2 has been under way in the U.S. and U.K. for at least ten years and, although medium-size simple circuits can now be built and operated with confidence, it is clear that the least satisfactory components are those concerned with the control and measurement of oxygen content. The use of the " cold trap " enables the oxygen content to be reduced to 10-20 ppm which appears to be marginally adequate and to achieve a lower figure than this a " hot trap " of some sort (either Zr or U) is necessary (705, 2291). None of the convenient oxygen content meters can be used at levels below 10-20 ppm.

Stage 3 of sodium reactor technology has presented problems the magnitude of which have only been realized fairly recently. For example the absence of a thermal boundary layer which enables high heat transfer coefficients to be obtained has proved to be an embarrassment rather than an asset. It can lead to non-uniform and unpredictable temperature variations and in severe cases to thermo-mechanical instabilities in heat exchange surfaces. It confers the ability to produce severe thermal shocks in all parts of a reactor, particularly under scram conditions. Consequently thermal shock analysis and the related problems of evolving satisfactory criteria for materials under these conditions is now emerging as a major design problem. Most of the experience with sodium heat exchangers has been gained in the U.S. and those in a good position to judge (2291) are not sanguine about our ability to produce large reliable units at an economic price. A large amount of experience, most of it successful, has been obtained with sodium pumps of the electromagnetic and mechanical varieties. Both types should ultimately prove reliable in spite of the difficulties experienced in SRE.

The reason for developing a reactor technology for liquid metals other than sodium (or the chemically similar NaK and lithium) lies in their ability to dissolve fissile material. The most natural solvent for uranium is bismuth, which has very attractive nuclear properties and which can also dissolve acceptable quantities of plutonium. The potentialities of such a technology for thermal reactors were described at the last Conference, and paper 2355 of the present conference reports progress made at Brookhaven National Laboratory, and describes briefly LMFRE-1, a 5 MW externally cooled reactor working between 400°C and 475°C.

Comparing the states of development of sodium and bismuth technologies it is clear that in the latter Stage 1 has not yet been passed. In order to use conventional engineering materials a mass-transfer inhibitor is necessary and much of the work at Brookhaven (2406) and at Harwell (270) is concerned with the development of inhibition techniques. It should be realized however, that when the container problem has been solved, much of the experience gained in Stages 2 and 3 of the sodium work can be used directly. Some of the circuitry developed at Brookhaven is outlined in paper 459.

The development of a liquid metal fuel either as a solution or a slurry has a fundamental advantage over an aqueous fuel—it opens up the possibility of a liquid fuelled fast reactor. Although bismuth is a possible carrier other possibilities are plutonium-magnesium eutectic and plutonium-iron (270). It is clear that much basic information is needed to solve the containment problems, but the reward for success could be very great.

Sodium-Cooled Thermal Reactors

The Sodium Reactor Experiment (SRE) described at the first Conference became critical in March 1957. Paper 452 details operating experience to date. Critical loadings were obtained with the reactor dry and " wet " and are compared with the figures obtained by calculation. The actual numbers of fuel elements given by the two methods are 21.1 and 22.2 respectively in the dry state and 28.3 and 32.6 in the wet state. The much greater discrepancy in the wet than the dry core is surprising in view of the fairly small total sodium cross-section.

Reactivity measurements indicate a positive isothermal temperature coefficient of 15×10^{-6}/°C and a negative prompt coefficient of 13×10^{-6}/°C. At the powers so far achieved (up to ¼ full power) the plant has proved very stable. Numerous minor troubles which developed in the sodium circuits are described, generally traceable either to

PAPERS LISTED

270 Frost, B. R. T., *et al.*; Liquid Metal Fuel Technology.
452 Faris, F. E., *et al.*; Operating Experience with the Sodium Reactor Experiment.
459 Isler, R. J., *et al.*; Engineering Experience at B.N.L. in Handling Uranium-Bismuth Reactor Fuels.
608 Olson, R. L., *et al.*; Sodium-Graphite Reactor Power Plant for CPPD.
705 Carter, R. L., *et al.*; Recent Developments in the Technology of Sodium-Graphite Reactor Materials.
2291 Smith, F. A.; Sodium Technology for Nuclear Power Plants.
2355 Williams, C., *et al.*; Liquid Metal Fuel Reactor and LMFRE-1.
2406 Klamut, C. J., *et al.*; Material and Fuel Technology for an LMFR.

oxide plugging or design weaknesses. Scram tests have shown the need to control coolant flow very carefully so as not to overstress materials and to this end variable magnetic brakes, automatically controlled, have been incorporated in the primary and secondary circuits. For a similar reason, a reversible electromagnetic pump is being inserted to control the moderator coolant flow more precisely. The intermediate heat exchanger has behaved less efficiently than expected due to bad flow distribution.

A paper of this nature giving operating experience is extremely valuable. As expected teething troubles have been encountered, but the real endurance test of the reactor system is yet to come; the integrated flux-times so far achieved are insignificant.

A progress report on the 75 MW (E) Sodium Graphite Reactor (SGR), (608) shows clearly how the lack of experience with large-scale sodium circuits and components inhibits the designer. Many decisions affecting this plant must await the outcome of SRE experience. Alternative types of mechanical pumps are to be tested, and stainless steel moderator cladding is being seriously considered as an alternative to zirconium. This must have a serious effect on neutron economy. A feature of the design is the use of valves in the primary coolant circuit.

(*Translations on page* 442)

Report from Geneva—8

Gas-cooled Power Reactors

IT is convenient to classify the U.K. schemes for gas-cooled power reactors in three main categories, beginning with the power stations already under construction which are based essentially on Calder Hall technology. In the second category are the detailed design studies for the so-called "advanced gas-cooled reactor" in which slightly enriched uranium oxide will be used as the fuel, with either stainless steel or beryllium as the canning material. Finally, there is the long-range scheme for a high-temperature gas-cooled reactor using ceramic fuel. Each of these three main categories involves the use of graphite as the moderating material. Mention should also be made, however, of a different type of gas-cooled reactor using heavy water as the moderator. This latter type fits into the general time-scale in the second of the three main categories as a possible alternative to the advanced graphite-moderated reactor.

The general paper (73) from the U.K.A.E.A. which lists the principal technical features and design parameters that have been modified or developed in going from the Calder Hall design to those of the four industrial consortia, includes also a note on the methods of tender assessment. It is evident that the Industrial Group of the U.K.A.E.A. has been giving a great deal of attention to this matter. An appendix discusses the problem of gas leakage from the pressure circuit of the Calder Hall reactors. Four papers (74, 75, 263, 264) outline in varying degrees the main design features and principal parameters of the first four U.K. commercial stations and information is given in each regarding major plant items, the general arrangement of the reactor core and the form of the fuel elements.

Paper 2331 gives a useful statement of general safety principles, together with a list of references to more detailed work, as applied to gas-cooled reactors of the Calder type. It would have been still more valuable, however, if the subject could have been discussed in relation to the additional problems which will arise with successive increases in reactor size, fuel rating, and working temperatures which will be experienced in future designs.

Reactor Physics

The methods of analysis used in reactor core calculations can, at best, be only approximate. In practice it is not possible, starting only with a knowledge of the nuclear cross-sections of all the reactor materials, to predict with accuracy the critical size and other major parameters of a reactor system. The normal procedure, therefore, is to use a relatively simple method of analysis based on a crude theory of neutron diffusion and to derive the working values of the various constants for the system by applying this over-simplified theory to the analysis of integral experiments on sub-critical and critical assemblies. The method is essentially one of interpolation and the accuracy of the parameters obtained in this way will depend not only on the accuracy of the experimental measurements but also on the soundness of the theory used and the range of the experiments. The situation must be reviewed periodically as new experimental data become available, for instance data obtained during the commissioning of a new reactor project. It is also desirable from time to time to review the method of analysis employed and to incorporate any improved theoretical techniques that may be feasible. It would be a mistake to suggest that any radical developments in reactor physics, as applied to graphite-moderated gas-cooled reactors, have been achieved during the past two or three years. There has, however, been a steady, if unspectacular, improvement in technique during this period and two U.K. papers (15, 40) give a lucid account of the latest situation so far as graphite-moderated reactors of the Calder Hall type are concerned.

Heat Transfer

One of the most striking features of the first industrial nuclear power stations in the United Kingdom, when compared with the Calder Hall design, is the large increase in thermal output. A large part of this advance has been due to the larger dimensions of the reactor core, associated with the use of a larger and thicker-walled pressure vessel, together with a greater degree of flattening of the neutron flux. At the same time an important advance has been achieved in the specific thermal rating of the fuel. This has resulted from the development of improved forms of finned fuel elements. The particular form of fuel element now favoured for its heat transfer properties involves the use of multi-start helical fins of fairly long lead together with longitudinal radial splitters located in the annular flow channel. These splitters, in the design described, are inserted in slots cut into the helical fins at regular intervals round the perimeter and extend to a position radially close to the wall of the flow channel. A full account is given (48) of the development of this type of fuel element together with a considered analysis of the physical principles underlying the design. Experimental results obtained in the course of development work with a similar form of fuel element have also been recorded (38). Recommended empirical correlations are given for the heat transfer coefficient and friction factor.

In addition to the steady-state design conditions for a power reactor the problems of transients in reactivity and temperature have to be carefully analysed. This subject, in which reactor physics and heat transfer are interrelated, is of vital importance to reactor control and to safety under fault conditions. A great amount of work is being done in this field at the present time and paper 21 on reactor heat transfer transient equations is one of the most useful theoretical studies to be published.

French Developments

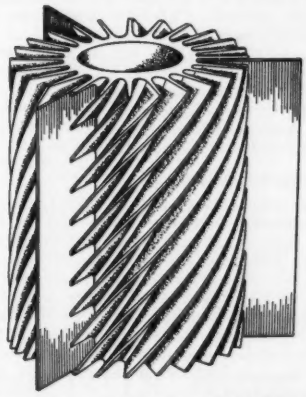
France has an enviable record of engineering achievement in the post-war years and it is significant that a policy has been followed to develop the gas-cooled reactor for power generation, which in broad outline is similar to that of the United Kingdom. A general description (1133) of the construction with further detailed information (1134) of the two reactors G2 and G3 at Marcoule are of particular interest on account of the use of pre-stressed concrete pressure vessels. The first nuclear station in France designed for commercial power generation, as opposed to by-product power generation from plutonium producing reactors, is that of Electricité de France at Chinon which is now under construction. Two reactors, EDF1 and EDF2 (1135) are being built on this site. In using natural uranium and magnesium alloy cans for the fuel elements, and in employing a vertical channel arrangement for the core with a conventional type of fabricated steel pressure vessel, EDF1 may be described as following the basic technology of Calder Hall. There are, however, a number of important differences in the design. Notably the design and arrangement of the heat exchangers is entirely different from Calder Hall and involves the use of a large number of individual shop-fabricated steam raising units each of 2 ft 1 in. diameter and 94 ft high. Another major difference is that the entire reactor unit and gas circuit for EDF1 is contained inside a steel sphere 180 ft in diameter (1199, 1201).

Whereas EDF1 is regarded as being still of an experimental character, it is intended that the second unit at Chinon, EDF2, will be the real prototype for further power stations using natural uranium fuel. EDF2, which will be completed 18 months after EDF1, will have a net electrical output of 167 MW.

Advances in Design

Two papers were presented at the conference (312, 450) describing design studies for advanced gas-cooled graphite-moderated reactors employing enriched uranium in the form of uranium oxide as the fuel and using either stainless steel or beryllium as the canning material. Both from the point of view of safety and of compatibility of materials, and also from the point of view of achieving higher heat ratings and lower specific capital costs, there is much to be said in favour of uranium oxide as the fuel for gas-cooled reactors. On this point there is general agreement among reactor designers. Opinions differ, however, on the choice of the canning material.

Considerable interest was shown at the conference in the paper presented by the U.K. (314) on the subject of achieving high working temperatures in gas-cooled reactors. No doubt this paper was intended primarily to stimulate discussion and it served this purpose in an admirable manner. Attempts to achieve gas outlet temperatures in excess of 600°C, however, will involve very great problems of engineering design and development. Quite apart from the reactor core itself, the difficulties of designing conventional items of plant in the gas circuit to operate at temperatures above 600°C without sacrifice of reliability and reasonably long life will be formidable in the extreme. It is difficult to understand the pre-occupation with the idea of a gas outlet temperature of 750°C and the use of gas turbines. While the idea of a free-running gas turbine driving the circulator in the gas circuit has many attractions and is probably well worth attempting in practice, there is no obvious case for using anything other than steam plant and steam turbines for the main power generating units in the foreseeable future.



Polyzonal spiral fuel can (Paper 48).

The case for steam plant, and the probable development of steam cycles appropriate to the various stages of development of the gas-cooled reactor, is clearly presented in paper 273. Table I in this sets out suitable steam cycles for reactors in which the gas coolant outlet temperature rises in steps of 50°C from the present level of around 350°C to an ultimate objective of 600°C. The authors show that in this latter case a super-critical pressure cycle with reheat would result in a station overall efficiency of 40.5%. The objective that is in sight with the use of steam plant in association with a fully developed advanced gas-cooled reactor is, therefore, attractive.

The general impression gained from the conference is that the gas-cooled reactor is very much alive and is capable of steady improvement and technical development for a long time to come. It is interesting to note that in moving towards the use of slightly enriched fuel in the form of uranium oxide, in place of natural metallic uranium, and in pushing up the specific rating of the fuel, the designers of gas-cooled power reactors are approaching quite closely to the fuel characteristics of the American types of PWR and boiling-water reactor. The two main rival types will thus become more directly comparable both in regard to their capital costs and their fuel requirements.

(*Translations on page* 442)

PAPERS LISTED

15 Cutts, B., *et al.*; Graphite Moderated Thermal Reactor Calculations for the Calder Hall Reactors.
21 O'Neill, T. J.; The Derivation of Reactor Heat Transfer Transient Equations for Gas-cooled Graphite-moderated Thermal Reactors.
38 Hughes, D. F., *et al.*; A Correlation of Heat Transfer for Finned Fuel Elements for Carbon Dioxide Reactors.
40 Campbell, C. G., *et al.*; Critical and Sub-critical Assembly Experiments with a Two-group Correlation of Results.
48 Ritz, H. L.; The Polyzonal Spiral Fuel Element.
73 Cunningham, J. B. W.; Current Re-designs of Calder Hall.
74 Millar, R. N.; Hunterston Power Station.
75 Arms, H. S., *et al.*; Hinkley Point Nuclear Power Station.
263 Vaughan, R. D., *et al.*; Bradwell Nuclear Power Station.
264 Ghalib, S. A., *et al.*; The Berkeley Power Station.
273 Wootton, W. R., *et al.*; Steam Cycles for Gas-cooled Reactors.
312 Moore, R. V., *et al.*; Advances in the Design of Gas-cooled Graphite-moderated Power Reactors.
314 Shepherd, L. R., *et al.*; The Possibilities of Achieving High Temperatures in a Gas-cooled Reactor.
450 Charpie, R. A., *et al.*; Design Study for a Graphite-moderated Gas-cooled Reactor Using Partially Enriched Uranium.
1133 Pascal, M., *et al.*; General Specifications and Original Aspects of Reactors G2 and G3.
1134 France: Design of the G2 and G3 Reactors.
1135 Roux, *et al.*; The Nuclear Power Stations of Chinon, EDF1 and EDF2.
1199 Lamiral, *et al.*; Pressure Vessel and Heat Exchangers of Chinon Nuclear Power Plant EDF1.
1201 Leo, *et al.*; Problems of Charge and Discharge with the EDF1 Reactor.
2331 Farmer, F. R., *et al.*; Safety Considerations for Gas-cooled Thermal Reactors of the Calder Hall Type.

Fast Reactors and Liquid Metals (Pages 437-9)

Systèmes de Métal Liquide

L'Union Soviétique rapporte sur cinq réacteurs rapides déjà construits ou en voie de construction, mais il est encore difficile d'estimer l'importance de l'effort russe dans cette voie. Les renseignements soumis sur les générateurs rapides américains et anglais permettent d'établir une comparaison intéressante sur les diverses méthodes d'affronter le problème de la stabilité et de la sûreté du noyau.

L'expérience sur SRE indique des progrès dans la technologie du sodium et met en valeur les difficultés qu'il reste à surmonter.

Malgré les avantages potentiels des combustibles de métal liquide, on estime maintenant que les difficultés sont énormes et qu'il faudra terminer une longue recherche de base avant de pouvoir démontrer la praticabilité du LMFR.

Flüssige Metal-Systeme

Die Soviet Union hat über 5 (fünf) Schnell-Reaktoren berichtet, die entweder bereits errichtet oder in Konstruktion begriffen sind, aber es ist noch immer schwierig, Tatsächliches über die jetzige Bedeutung russischer Bestrebungen auf diesem Gebiet zu erfahren. Von amerikanischer und britischer Seite vorgelegte Berichte über Schnell-Generatoren geben interessante Vergleichsmöglichkeiten hinsichtlich der Verschiedenartigkeit der Methoden im Studium des Problems der Kern-Stabilität und-Sicherheit.

Die Erfahrung mit dem SRE gibt Hinweise auf die Entwicklung der Natrium Technik und unterstreicht die Probleme, die noch die Lösung erwarten.

Trotz der bedeutenden Vorteile flüssiger Metal-Brennstoffe ist man sich jetzt dessen bewusst, dass man hier vor ungeheuren Problemen steht, und dass noch viel Forschungsarbeit erledigt werden muss, ehe die praktische Verwendbarkeit der LMFR (FMSR-Flüssig-Metal-Schnell-Reaktor) bewiesen werden kann.

Sistemas de Metal Liquido

La Unión Soviética informa sobre cinco reactores rápidos ya cinstruidos o en curso de construcción, pero se hace difícil estimar la importancia del esfuerzo ruso en este campo. Los informes sometidos sobre generadores rápidos nos permiten establecer una interesante comparación sobre las diversas formas de atacar los problema de establidad de núcleo y seguridad.

La experiencia en SRE indica el desarrollo que se viene logrando en tecnología del sodio y recalca los problemas que todavía han de ser vencidos.

Pese a las ventajas potenciales del combustible de metal liquido, se estima ahora que los problemas son en verdad formidables, y que se habrá de completar mucha investigación básica antes de que se pueda demonstrar la practicalidad del LMFR.

Gas-cooled Power Reactors (Pages 440-1)

Réacteurs d'Energie Refroidis au Gaz

Le réacteur refroidi au gaz a été en grande partie mis en valeur par Grande Bretagne. Les difficultés se rapportant à l'installation du genre Calder furent discuter à la Conférence et l'on donna aussi des détails sur les centrales électriques commerciales. Le réacteur refroidi au gaz plus avancé et le réacteur refroidi au gaz de haute température furent aussi revisés et des avant-projets pour ce dernier furent proposés à titre d'essai.

Pendant ces dernières années, on a observé une amélioration constante dans la compréhension des problèmes physiques de ces réacteurs; on a aussi fait un progrès considérable dans les accessoires spécifiques de l'équipement, tels que les couvertures de combustibles. Les réacteurs britanniques peuvent être comparés aux réacteurs en construction ou déjà terminés en France, où les avantages et les problèmes particuliers du récipient de béton sous pression sont considérés.

Der Gas-gekühlte Kraft-Reaktor

Der gas-gekühlte Kraft-Reaktor gelangte vor allem in dem Vereinigten Königreich zur Entwicklung. Bei den Konferenzen wurden Probleme erörtert, wie man sie im Calder Werk findet, sowie Einzelheiten über die Industrie-Kraftwerke. Auch die im gas-gekühlten Reaktor vorgeschrittenen Entwicklungen, sowie der warmfeste, gas-gekühlte Reaktor wurden besprochen und die vorläufigen Entwürfe für den letzteren annähernd beschrieben.

Die letzten Jahre zeigen das ständig wachsende Mass unseres Verständnis für die physikalischen Probleme solcher Reaktoren, sowie eine bedeutende Entwicklung ihrer spezifischen Ausrüstung, wie z.B. der Brennstoffbehälter.

Reactores de Energia Enfriados por Gas

El reactor enfriado por gas ha sido desarrollado en gran parte en el Reino Unido. En la Conferencia se discutieron problemas asociados con la instalación del tipo Calder Hall y se ofrecieron detalles de las estaciones de energía comercial. El reactor más avanzado de enfriamiento a gas y el reactor del alta temperatura enfriado a gas fueron también motivo de discusión haciéndose diseños tentativos de este último.

En los últimos años se ha observado una mejora progresiva en nuestro conocimiento de problemas físicos de estos reactores y se ha observado asímismo un advance notable en accesorios específicos del equipo, tales como las envolturas de combustible.

[Nuclear Materials (Pages 443-8)

Materiaux Nucléaires

Depuis la dernière conférence, on a fait un effort considérable pour développer la production de combustibles nucléaires et de matériaux de couverture, ainsi que dans l'étude des dommages causés par la radiation et sur les problèmes de compatibilité.

La technologie de l'uranium naturel, qui est d'un intérêt particulier dans Grande Bretagne, a progressé considérablement, mais on porte plus attention à la production de combustibles céramiques, et un grand nombre de données ont été accumulées sur l'oxyde d'uranium et sur son comportement sous conditions réactrices en plus de sa capacité de réaction avec des réfrigérants.

On a apporté une grande attention aux matériaux de couverture tels que le magnésium, le zirconium, l'acier inoxydable; le plus récent matériel de ce genre, le béryllium, est en train d'être développé au point de rendre plus rapprochée la production de couvertures raisonnablement ductiles.

De mêmes manières, des modérateurs tels que le graphite et l'eau lourde, ont fait l'objet d'investigations intenses et les résultats sur le comportement du graphite sous irradiation et du méchanisme d'emmagasinage d'énergie ont été largement, sinon complètement, compris.

Werkstoffe und Brennstoffe in der Atomkraft-Technik

Seit der letzten Konferenz ist beträchtliche Entwicklungs-Arbeit auf dem Gebiet der Produktion von Brennstoffen und von Hülsen-material und im Studium von Strahlungsschäden und Problemen des gegenseitigen Einflusses von Werkstoffen aufeinander geleistet worden.

Die Technologie von natürlichem Uran, von besonderem Interesse in Grossbritannien, zeigt beträchliche Fortschritte, jedoch hat man noch mehr die Produktion von keramischen Brennstoffen im Auge, und man hat bereits eine grosse Menge von Daten über Uranoxyd und sein Verhalten unter den im Reaktor vorhandenen Bedingungen zusammengebracht und weiter, wie es mit verschiedenen Kühlmitteln reagiert.

Hülsen-Werkstoffe wie Magnesium, Zirkon, rostfreier Stahl haben einen grossen Teil der Aufmerksamkeit in Anspruch genommen, und das neueste Material auf diesem Gebiete, Beryllium ist soweit entwickelt worden, dass die Herstellung von genügend nachgiebigen Hülsen nicht mehr zu lange dauern wird.

In derselben Weise sind Moderatoren wie Graphit und schweres Wasser der Gegenstand eingehender Untersuchungen gewesen, und auf Grund der Resultate hat man nun das Verhalten von Graphit unter Bestrahlung und den Mechanismus der Energie-Ansammlung zum grossen Teil, wenn auch nicht vollkommen verstanden.

Materiales Nucleares

Desde que se celebró la última Conferencia, se han hecho esfuerzos considerables en el desarrollo de la producción de combustibles nucleares y materiales de cobertura, y en el estudio de los daños por radiación y problemas de compatabilidad.

La tecnología del uranio natural, de especial interés en Gran Bretaña ha avanzado notablemente, pero se presta mayor atención a la producción de combustibles cerámicos, y se han recogido multitud de datos sobre el óxido de uranio y su comportamiento bajo condiciones de reactor además de su capacidad de reacción con los refrigerantes.

Los materiales de envoltura tales como magnesio, zirconio, acero inoxidable, han sido estudados detenidamente y el material más novel en esta gama es el berilio, que se viene desarrollando al punto en que la producción de envolturas razonable dúctiles no se encuentra ya muy alejada.

En la misma forma los moderadores, como el grafito y el agua pesada, han sido intensamente investigados y los resultados sobre el comportamiento del grafito bajo irradiación y el mecanismo de almacenaje de energía, si no completo ya, es bastante bien comprendido.

Report from Geneva—9

Nuclear Materials

METALLIC FUELS

IN the United Kingdom emphasis has been placed on the achievement of a grain refined uranium to minimize fuel surface wrinkling and consequent localized strains in a "soft" can; alloying additions of Cr, Fe and Zr are most effective as grain refiners, in conjunction with suitable heat treatments (27). While the soundness of this approach appears to be confirmed by the findings at Windscale on the dependence of wrinkling on grain size (50), American work suggests that even better grain refinement can be achieved at the cost of alloying (713). Interest has been less concentrated in the United Kingdom on directional fuel growth, although care has been taken to ensure that heat treatment of the production fuel does not produce preferred orientation (306). In the United States, where worked uranium is the norm, some effort has been directed to this problem (713). The swelling of metallic fuels is a serious problem in reactors with high fuel and coolant outlet temperatures and much scientific effort has concentrated on the understanding of the basic factors.

The degree of swelling experienced in particular circumstances can be explained in terms of the growth of fission gas bubbles at a rate determined by the creep strength of the metal, providing that allowance is made for such factors as the effect of thermal cycling on creep, the presence of inclusions, and the onset of internal cracking (51). There appears to be some conflict between experience in the United Kingdom where dilute alloying of uranium has not appeared to be effective in reducing swelling, and in the United States where swelling rates are reported to be halved (617). Alloys of uranium in thorium appear to give less swelling than uranium or uranium alloys (617). Much background work has continued on the measurement of the basic properties of metallic fuels. A wide range of physical and mechanical properties of uranium and its alloys has been reported by various authors (49 and 2230). The physical metallurgy and properties of plutonium have also been described (1452, 1081).

Wide interest is shown in the utilization of plutonium in power producing reactors and the importance of this development in the frame work of world power needs has been described (2021). Much consideration has been given to the possible forms in which plutonium might be used, ranging from alloys with other metals, and in particular uranium (2021) through ceramics and cermets (1452) to molten or fluid fuels with the possibility of continuous feed and reprocessing (2021).

In the field of uranium isotope separation, very full descriptions have been given of the problems involved in UF_6 technology, including the development of porous barriers, corrosion aspects, and the chemical engineering considerations related to process design and the choice of the best plant and stage characteristics (1262). Methods of barrier manufacture are given, together with the measurement techniques required for performance estimation. Other methods of isotope separation have been described, including a separation nozzle process (production of an expanding supersonic jet) (1002), and the ulta-centrifugation method (1121).

PAPERS LISTED

27 Jepson, M. D., *et al.*; Transformation Behaviour of some dilute uranium alloys.
49 McIntosh, A. B., *et al.*; High Temperature Properties of Uranium and its Alloys.
50 Eldred, V. W., *et al.*; Fuel Element Behaviour under Irradiation.
51 Burns, W. G., *et al.*; The Effect of fast electrons and fast neutrons on polyphenyls at high temperatures.
306 Hardy, H. K., *et al.*; The Assessment and Testing of Fuel Elements.
617 Hayward, B. R., *et al.*; Effect of Burnup on metallic fuel elements operating at elevated temperatures.
713 Chiswick, H. H., *et al.*; Advances in the Physical metallurgy of uranium and its alloys.
1002 Beeker, E. W., *et al.*; The Separation-Nozz'e Process.
1081 Gardner, H. R., *et al.*; The Tensile Properties of Pure Plutonium and Plutonium-Aluminium Alloys.
1121 (Netherlands) The Separation of uranium isotopes by ultracentrifugation.
1262 Frejacques, C.; Main results obtained in France in the development of the gaseous diffusion process for uranium isotope separation.
1452 Waldron, M. B., *et al.*; Plutonium Technology for Reactor Systems.
2021 Hall, D. B., *et al.*; Plutonium Fuels for Fast Reactors.
2230 Konobeevsky, S. T., *et al.*; Some physical properties of uranium, plutonium and their alloys.

NON-METALLIC FUELS

SEVERAL papers (142, 182, 192, 318, 587, 783, 1011, 1165) originating from six countries discuss the methods of obtaining high density uranium dioxide shapes. Most of the work has been by cold-pressing of powder followed by sintering and the most noticeable feature is the more general use of low sintering temperatures (around 1,400°C), still getting densities better than 95% of the theoretical value. The size and surface activity of the powder are major factors controlling sintering behaviour. As a result, considerable importance has been attached to the development of commercially practical processes which give a consistent, fine particle powder, as well as to methods of measurement to provide means of production control. In the Canadian process (192) now being tested on a commercial scale, particles less than 1μ are considered desirable; these give densities of 95% theoretical under conditions where 75 μ particles would only give 70% theoretical. Similarly, very fine powders (1165) have provided 95% densities after sintering in purified hydrogen at 1,200-1,400°C. Very high densities at low sintering temperatures were obtained by sintering in steam (142, 192).

It is pointed out (192) that the expensive production of accurately sized dense pellets of UO_2 seems to be unwarranted as they quickly break up due to thermal stress under irradiation. Methods are described of preparing fuel elements by rotary swaging of suitable UO_2 powder in aluminium or Zircaloy sheaths. These give a material of 95% theoretical density, but thermal conductivity is only 40% of that of sintered 95% dense material. Similar methods are described by Murray and Williams (318) who also give some details of a warm-pressing route which can give accurately sized pellets without a grinding operation. The swaged powder material behaved satisfactorily in irradiation tests (193), the oxide apparently sintering during irradiation.

New results have been published on the thermal conductivity of uranium dioxide; a property which is most important in the design of fuel elements. At least in room temperature tests, it has been confirmed that material containing excess oxygen (e.g. $UO_{2.16}$) has thermal conductivities only a half of the stoichiometric material (192, 318). Determinations at AERE (318) on 95% dense stoichiometric UO_2 gave values of 0.0078 cal/sec, °C, cm at 800°C and

0.0058 at 1,200°C (values corrected to theoretical density). Experiments (141) showed that irradiation to 10^{18} n/cm^2 at 300°C produced little effect on the thermal conductivity of a high-density specimen (10.5 g/cm^3) under irradiation conditions which had produced marked conductivity changes in earlier samples; thermal stress alone reduced the thermal conductivity to a very low value similar to that of UO_2 powder. Previously, little information has been generally available on the irradiation behaviour of uranium dioxide fuel elements. For this reason details of the behaviour of sheathed UO_2 pellets produced by a variety of methods when irradiated under pressurized water conditions are of great interest (193). Such fuel elements have been irradiated to 5,000 MWd/tonne uranium with no gross harmful effects. There were marked differences in behaviour between different samples, depending on size, rating, fuel-sheath clearance and composition. Radial cracking was common, and in the more highly rated elements central voids formed.

The accumulation in the fuel element can of the inert gases which arise from fission products is a dominant factor in determining the life of the fuel element. The amount of gas released in a particular irradiation is thus of considerable importance (1013).

Attempts have been made to correlate information found experimentally with calculations. The factors involved in the calculation are the diffusion coefficients of the rare gases and the temperature gradient across the specimen. In the past, lack of correlation has usually been ascribed to errors in temperature estimation, but Dr. Lewis of Chalk River, in a contribution to the discussion, produced evidence of differences even where the temperature assumed was wholly justified by experiment. Diffusion coefficients from a number of laboratories agreed to within a factor of two or three, so in the Canadian results some further factor was involved. They believed this to be the "stirring" effect resulting from the energy imparted to the gas atoms by fission fragments and had been investigating this effect by studying the distribution of the solid daughter products from rare gas isotopes with a variety of half-lives.

Uranium Carbide

Uranium monocarbide can be prepared (1162) by hot pressing uranium-graphite mixtures in graphite dies and reacting at 900°C. By control of the uranium and graphite powders and by careful mixing the very high density of 13.4 g/cm^3 (98% theoretical), and a hardness of 700 V.P.N. has been obtained. This material when heated in CO_2 for six hours at 500°C showed only one tenth of the attack found in pure uranium under the same conditions. In contrast results are quoted (318) of the action of CO_2 on UC specimens of 10.98 g/cm^3 density which showed very rapid corrosion at 500°C, about 100 times faster than uranium metal under similar conditions. Amongst the properties of UC of 75% theoretical density discussed (964), the thermal expansion was given as 10.4×10^{-6} from 20-1,000°C and the thermal conductivity 0.080 cal/sec, °C, cm at 60°C decreasing to 0.050 at 265°C.

Dispersed Fuels

Interest is increasing in non-metallic fuel particles dispersed in a ceramic matrix. The desired properties for the matrix material of dispersed fuels for high temperature use have been discussed in detail (318). It is concluded that beryllia is a most attractive matrix for UO_2 for temperatures above 600°C, magnesia and alumina also being considered. Fresh determinations of the phase diagrams UO_2-Al_2O_3, UO_2-BeO, UO_2-MgO (2193) are of interest in this connection. These systems have also been discussed in relation to the fabrication of fuel elements with ceramic matrices and the preparation and properties (including irradiation behaviour) of UO_2-graphite, UO_2-ThO_2 and UO_2-SiC.

A technique for the production of fuel elements containing uranium dioxide particles dispersed in stainless steel (784), consists in producing a blend of stainless steel powder and UO_2 powder which is subsequently fed through horizontal rolls to make a cold pressure-welded composite.

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142 Runfors, U., *et al.*; The Sintering of uranium dioxide.
182 Schönberg, S., *et al.*; Production of Uranium Dioxide Bodies for Fuel Elements.
192 Chalder, G. H., *et al.*; The Fabrication and Properties of Uranium dioxide fuel.
193 Robertson, J. A., *et al.*; Behaviour of Uranium Oxide as a Reactor Fuel.
318 Murray, P., *et al.*; Ceramic and Cermet Fuels.
587 Solli, O.; Preparation and Sintering of UO_2.
783 (U.S.A.) Fabrication of uranium dioxide.
784 Shapiro, S.; A new fabrication technique for the production of stainless steel oxide dispersion fuel elements.
964 Boettcher, A., *et al.*; Some Properties of Uranium Monocarbide.
1011 (U.S.A.) Porosity changes associated with sintering of UO_2 components.
1013 (U.S.A.) Diffusion and solubility of rare gases in uranium dioxide.
1162 Dubuisson, J., *et al.*; Preparation par Frittage sous charge de Cermets U-UC et de Monocarbure Stoechiometrique.
1165 Bel, A., *et al.*; Contribution à l'étude du Frittage de l'oxyde d'uranium.
2193 U.S.S.R. U Binary phase diagrams for uranium, aluminium and beryllium oxides.

FUEL ELEMENTS

INTERESTING fuel element basic designs include a rod type UO_2 element, canned in Zr alloy, for use in water cooled power reactors (2196), an independently supported element using graphite sleeves (1523), and a molten Pu system, using the Pu-Fe eutectic in a Ta heat exchanger with Na cooling (445).

The field of fuel element development is too diverse to cover fully in this short review, but a number of highlights include the possibility of phase inversion and reduced swelling in pile by the use of U-Nb-Zr alloys (1924), the favourable stability of Th—10% U alloys under irradiation (785), and the development of ceramic fuels to give much reduced capital cost per kilowatt and improved irradiation stability (312).

Multitudinous fabrication techniques for a wide range of fuel element applications have been described, including the manufacture of plutonium sandwich and cylindrical spike elements (1776), powder metallurgy techniques (1740) and active handling in the fabrication of U^{233} on the kilogram scale (1048).

Particular attention should attach to the description given of the behaviour of Calder fuel elements in service (50), which clearly demonstrates the detailed analysis of observed patterns of fuel element behaviour, and regards development in terms of continuous diagnosis and improvement.

PAPERS LISTED

50 Eldred, V. W., *et al.*; Fuel Element Behaviour under Irradiation.
312 Moore, R. V., *et al.*; Advances in the Design of Gas-cooled Reactors.
445 Kiehn, R. M., *et al.*; A proposal for a one megawatt reactor experiment utilizing a molten plutonium fuel.
785 Hayward, B. R., *et al.*; Thorium-Uranium Fuel Elements for SRE.
1048 (U.S.A.) The Fabrication of Uranium-233 on a kilogram scale.
1523 Wootton, K. J., *et al.*; The Development of the Hunterston Fuel Element.
1740 (Yugoslavia) Reduction of Uranium from carbonate solutions with hydrogen using UO_2 as catalyst.
1776 Wick, O. J., *et al.*; Plutonium Fuels Development.
1924 Thomas, D. E., *et al.*; Properties of Gamma-phase uranium alloys.
2196 Ambartsumian, R. S., *et al.*; Fuel Elements for Light water cooled and moderated reactors of Atomic Power Stations.

CANNING MATERIALS

IN thermal reactors of the Calder Hall type, the magnesium can acts as an extensible envelope and must accommodate strains due to growth, swelling and bowing of the fuel without failure. Adequate ductility is thus required although this must be coupled with good creep strength at the highest operating temperatures to prevent fin streamlining. Economic operation of power reactors may necessitate that the fuel elements should be shuffled from "hot" to "cold" positions so that grain growth at the

highest temperatures is undesirable in so far as this may reduce the can ductility at the lower temperatures. Data presented on Magnox A12 (305, 1455) indicate the desirability of improved ductility at the lower operating temperatures and this is being obtained by means of grain refinement. Compared with A12 the grain size stability of magnesium alloys containing zirconium, and their ductility at the lower operating temperatures have been shown to be superior. The creep resistance of these alloys, however, is lower than that of A12 at the higher temperatures. This can be remedied by the addition of manganese within the limits imposed on grounds of neutron economy while still maintaining the high ductility. Such alloys are shown to be readily weldable and exhibit good grain size stability up to 500°C.

Beryllium

The very low thermal neutron absorption cross-section of this material makes it an attractive canning material. There are, however, a number of problems associated with its low ductility and fuel compatibility which are currently receiving attention. The ductility is influenced by impurity content and a new approach to the production of high purity beryllium is by vacuum distillation and condensation on to surfaces held at carefully controlled high temperatures (2051). This is particularly useful where the vapour pressures of the impurities differ only slightly from that of the beryllium, and it is stated that material with a total impurity content of 200 ppm can be obtained on a commercial basis by such a process. The electrolytic production of beryllium can be improved by adoption of a system (717) in which the refined metal is dissolved at a mercury cathode, the beryllium amalgam being continuously separated by filtration. Various shapes can be directly produced by vacuum hot pressing of the amalgam or, alternatively, powder is obtainable by vacuum distillation. This process has the advantage of being continuous and overcomes the problems associated with the occlusion of chloride from the electrolyte. An advanced fabrication technique for beryllium which may ultimately be capable of eliminating the brittle welds in beryllium cans has been described (320). Powder of a critical particle size distribution is sintered at about 1,200°C for six hours in graphite moulds without the application of pressure. The technique is simple, versatile and economic in operation and is capable of producing shapes of high length/diameter ratio more readily than by hot pressing. The feasibility of producing fuel elements by sintering the powder directly round a uranium ceramic core has already been demonstrated on small specimens, but the scaling-up of the process will present several problems. At present, the process is critical in respect of particle size distribution and offers less control of sintered dimensions than vacuum hot pressing, but it is considered that closer control of powder production may alleviate these difficulties. Fabrication of beryllium by casting has also been investigated (2048) and details given of a vacuum induction furnace, suitable for this purpose, to which was attached a centrifugal casting machine which also operated in vacuo. In view of the low ductility of beryllium in the cast state, it is unlikely that the process will ever have direct application to the production of fuel element cans.

Zirconium and its Alloys

Zirconium is of interest both for use in aqueous solution reactors and also as a structural material in gas-cooled thermal reactors. Material in a very high state of purity is normally required for nuclear reasons and also because of the influence of minor impurities on the mechanical properties. The separation of the rhodanides of hafnium and zirconium (1003) was achieved by a liquid-liquid extraction method, this being followed by the precipitation of zirconium hydroxide, calcination and chlorination. Reduction of the chloride with a sodium-magnesium mixture in a Kroll-type process yielded material containing less than 30 ppm hafnium and which had a hardness of 125 V.D.H. Appreciable refining of zirconium with respect to other minor impurities has also been demonstrated by the electrolysis of molten salts under an inert atmosphere (698). Fluoride baths were claimed to give superior metal to chloride baths and anode material with a hardness of 220 V.D.H. yielded cathode deposits with very low hardness values in the range 73-78 V.D.H.

Technological information on the double consumable-arc melting of Zircaloy and its subsequent fabrication was also presented and the superiority of vacuum melted alloys, as compared with those melted under argon at atmospheric pressure, demonstrated.

Much effort has been devoted to the study of the corrosion resistance of zirconium alloys and their creep properties. It has been shown that alloying with niobium, palladium or platinum confers higher corrosion resistance to aqueous uranyl sulphate solutions than is exhibited by Zircaloy 2 and the Zr-Nb alloys can be heat treated to give high tensile strength coupled with reasonable ductility (1993). It is necessary, however, to make small additions of palladium or molybdenum in order to make such alloys weldable. Other workers (2046) have also indicated that the corrosion resistance of zirconium in superheated water is improved by additions of tin, niobium, chromium and iron. For use as a structural member Zircaloy 2 is shown to have useful strength but lacks adequate corrosion resistance in CO_2 at temperatures of 400°-450°C. The addition of up to 1% copper has been shown to improve the CO_2 corrosion resistance while the creep strength of such alloys can be raised to the level of Zircaloy 2 by the addition of $\frac{1}{2}$-1$\frac{1}{2}$% molybdenum (1455).

Niobium

For use as a fast reactor canning material, niobium is required to exhibit both high temperature strength and also adequate ductility to allow the cans to deform up to predetermined limits without fracture. It has been shown (305) that the ductility of production niobium falls to a minimum value at 500°C, this being attributed to strain ageing caused by interstitial elements. Evidence has also been presented which suggests that ageing effects observed at 600°C and 700°C are due to the precipitation of oxide from solid solution. Attention is therefore being directed towards improving the ductility by lowering the gas content. Material has been produced in small experimental quantities with 0.001% oxygen and 0.004% nitrogen by electron bombardment melting. The hardness of the latter material was ~40 V.D.H. as compared with 90 V.D.H. for normal production material. Preliminary results of alloying studies have indicated that appreciable modification of both strength and ductility can be achieved if this is necessitated by operational experience.

Work was described on the production of ductile niobium (and vanadium) from the pentoxides, which are claimed to be the easiest compounds to prepare in the state of highest purity (1274). While calcium reduction has been used to obtain ductile vanadium, the reduction of niobium pentoxide was shown to be more readily carried out with niobium carbide. This material, after consumable arc melting, had a hardness of 87±3 V.D.H. which is virtually identical with that of material already in commercial production (305).

Current work which is being carried out on iron-aluminium base alloys is stated (707) to show promise of yielding materials which have satisfactory high temperature strength and ductility and this fact coupled with their cheapness, high corrosion resistance, moderate neutron capture cross-section and ease of reprocessing may make them competitors with stainless steels and zirconium alloys for high temperature use in oxidizing atmospheres.

Aluminium alloys and stainless steels were also the subjects of several papers but these were restricted to the discussion of corrosion problems.

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320 Barrett, T. R., *et al.*; Pressureless Sintered Beryllium Powder.
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707 Maxwell, W. A.; Iron-aluminium Base Alloys for Reactor Components.
717 Holden, R. B., *et al.*; A continuous electrolytic process for the preparation of beryllium metal.
1003 Beeker, M., *et al.*; The Production of Reactor Grade Zirconium metal.
1274 Joly, M. F.; Procedes de Fabrication du vanadium et du niobium ductiles a partir de leurs oxydes.
1455 Olds, G. C. E., *et al.*; Mechanical Properties of Alloys of Magnesium and Zirconium.
1993 Adamson, G. M., *et al.*; Recent advances in the metallurgy of zirconium and titanium alloys of special interest in reactor technology.
2046 Ivanov, O., *et al.*; Structural and properties of zirconium alloys.
2048 Ivanov, E. S., *et al.*; Melting and Casting of Beryllium.
2051 Sinelnikov, K. D., *et al.*; Refining Beryllium and other metals by condensation on heated surfaces.

MODERATORS

INTEREST in graphite has continued at a high level. The manufacture of reactor graphite in France (1168), and in Japan (1327) has been described with details of the physical and mechanical properties of the material produced; comprehensive data on the mechanical properties of a range of graphites in the temperature range 20° to 2,800°C have also been discussed (702). Creep laws have been determined both in tension and compression in the temperature range 2,000°C-2,500°C, and modes of failure studied.

High-purity graphite with density in the range 1.85-1.90 g/cc has been produced in America in sections up to 20 in. diameter. The main value of such a material is not in reduced chemical reactivity, but in its low permeability to gases and liquids. With the properties quoted (708, 716) it may have an application in liquid metal fuelled reactors as a containing material, and in fuel elements fabricated with uranium dispersed in a matrix of graphite for high-temperature gas-cooled reactors.

An important group of papers deals with the effect of neutron irradiation on the physical and mechanical properties of graphite, and procedures for the release of stored energy. Wigner release in Windscale up to September, 1957, is described (1456), together with the procedure adopted in BEPO (1805) and parallel American experience in the B.N.L. Reactor (462). Davidson and Losty (28), who previously attempted an explanation of variations in the elastic modulus of graphites manufactured from a wide range of different raw materials in terms of the relative movement of the layer planes of the crystallites, have now carried out neutron irradiation of graphite specimens in the form of springs and demonstrated that the changes in modulus observed are sensitive to the heat treatment of the specimen prior to irradiation, particularly for treatments above 2,200°C. As a result they have attempted an extension of their original hypothesis to account for the changes in modulus under irradiation. Stress relaxation effects observed during constant strain experiments on graphite springs under irradiation are also discussed. The extent of changes in thermal and electrical conductivity, crystallite properties, dimensional stability and stored energy of reactor grade graphites is a function of the temperature of irradiation. In general the effects decrease with decreasing temperature (614). Many properties tend to saturate, and final property values have been determined for long exposures, up to 5,000 MWd/t at 600°C.

In the field of gas-graphite reactions (1778) changes in the chemical reactivity of graphite brought about by fast neutron irradiation are interpreted in terms of the displaced atoms and vacancies produced. The graphite oxygen reaction has been studied in some detail, thermal rates being determined on virgin graphite and on material irradiated to 4×10^{20} nvt. Parallel experiments have been made in the presence of γ rays (2×10^5 r/h), and the acceleration factors determined. Differences in the mechanism of burning behaviour between virgin and irradiated graphite have been observed.

A second paper on the chemical reactivity of graphite (303) deals with its reactions with carbon dioxide, and includes sections on the mechanism of the thermal reaction, methods of reducing the thermal reaction rate, studies under irradiation up to 350°C, and an account of an in-pile model channel experiment which enabled predictions to be made on the extent and distribution of carbon transfer in the Calder Hall reactors. Experiments conducted during the start-up of Calder are also reported; these gave rates of carbon monoxide production in reasonable agreement with predictions.

Another approach to the problem of protecting graphite from oxidation is by the use of carbide coatings (1428). Uniform crack free coatings of Ta, Nb and Zr carbides have been produced by a vapour deposition technique.

Heavy Water

The success of current boiling reactors has led to serious consideration of heavy water boiling reactors using natural uranium fuel. However, the cost of heavy water production is still formidable, and a study by C.E.A. in France examining the problems and relative merits of various separation processes is of interest. The study (1261) does not appear to have yet progressed beyond the pilot plant stage. An important contribution to the technology of boiling heavy water reactors is the project at Halden, in Norway (559), where the reactor is in the commissioning stage. The reactor vessel and the heavy water circuit are designed for 230°C steam operations, while steam for commercial utilization is raised in the secondary light water circuit. The reactor operates on natural uranium fuel rods one inch in diameter canned in aluminium alloy. This imposes an upper limit of operation of 150°C for the first charge from the compatibility viewpoint. The second fuel charge will probably consist of UO_2 pellets canned in steel. Approximately 16 tons of heavy water will be contained in the primary circuit of the 10 MW reactor.

A more ambitious design study on a 1,000 MW heavy water boiling reactor with nuclear superheat has been made at Argonne (463). This is planned to work with near natural uranium fuel and a high conversion ratio, possible with a heavy water moderator. The proposed design features a pressure tank boiling reactor with a superheating zone located within the slightly enriched oxide fuel core. The saturated steam from the boiling zone of the core enters the upper steam dome of the tank, and then passes through the superheating channels down into the lower plenum chamber and out to the turbine; a number of methods of recirculating the boiling water have been proposed.

A second design study, this time by the du Pont Company (610), is for a pressurized heavy water moderator reactor, utilizing natural uranium in the form of a 2% zirconium-uranium alloy canned in Zircaloy 2. As designed, heavy water circulates up through a pressure tank where it acts

as moderator, then down through the fuel assemblies to a heat exchanger whence it is recirculated.

Beryllia

The technology of beryllium oxide and UO_2-beryllia ceramics is being actively developed in several countries. Apart from its excellent moderating properties beryllia is notable for its high thermal conductivity and thermal shock resistance compared with other refractories, together with its good corrosion resistance to most oxidizing and reducing gases. Cold compacting and sintering, hot compacting, and slip casting (319) are possible methods for the fabrication of beryllia components from powders prepared by decomposition of the hydroxide. The effect of calcination temperature of the hydroxide as affecting hot and cold compacting properties is discussed in detail. Problems arise in sintering to high density and the maintenance of close dimensional tolerances during firing. A rather more *ad hoc* approach has been adopted by American workers (2002). Techniques for the production of thin-walled tubes are discussed. In examining the effect of neutron irradiation on beryllia, French workers (1159) have concentrated on the measurement of thermal conductivity coefficient and thermal diffusivity coefficient, while workers at Argonne (621) have measured gross dimensional changes, lattice dimensions, compressive strength, elastic modulus, specific heat, thermal conductivity and magnetic susceptibility changes not only of pure beryllia but of 2% UO_2-98% BeO and 10% UO_2-90% BeO. All properties of pure beryllia except the thermal conductivity were affected only slightly after a fast neutron dosage of 3.6×10^{19} nvt. The BeO-UO_2 samples, of interest as potential homogeneous fuel moderator assemblies, were subject to much greater changes in properties due to fast fission fragment damage. A large amount of data is available on corrosion rates of beryllia in air, pressurized water and liquid sodium in paper 1147.

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303 Anderson, A. R.; Chemical Studies of Carbon dioxide and graphite under Reactor Conditions.
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463 (U.S.A.) Design studies on heavy water boiling reactors with nuclear superheat.
559 Hidle, N., *et al.*; The Halden Boiling Heavy Water Reactor.
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716 (U.S.A.) Low permeability graphite for reactor use.
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2002 (U.S.A.) Recent advances in the technology of beryllium oxide ceramics.

STEELS

THE new information presented at Geneva on reactor structural materials concerned mainly the effect of reactor conditions. Both Trudeau (190) and Wilson (1978) present new data on the effect of irradiation on the mechanical properties of a variety of steels; in all cases cited, there was an appreciable increase in the notch-ductility transition temperature (the temperature for change from ductile to brittle behaviour) after irradiations greater than 10^{18} fast neutrons/cm^2, the magnitude of this change being dependent on the steel composition and heat-treatment condition. Wilson found a 0.25%C steel was less embrittled by irradiation in a fine grained condition; he also considered an aluminium-killed steel was less damaged than a silicon-killed steel. Trudeau showed that a low carbon medium alloy steel suffered less irradiation damage in the quenched and tempered condition than in the normalized and tempered condition. He also irradiated ASTM-A201 mild steel at 50°C to 6.5×10^{19} nvt and got an increase in transition temperature of 100°C; this was slightly further increased by post-irradiation annealing at 260°C but there was appreciable recovery on annealing six hours at 335°C. There is thus the possibility of extending the life of a reactor pressure vessel by periodic thermal treatments to remove irradiation damage. Wilson considered the weld and heat affected zone may be more sensitive to irradiation effects than the body of a plate; in one example an increase of 200°C in transition temperature of a weld heat-affected zone resulted from irradiating to 7.6×10^{19} nvt at a temperature of less than 100°C.

High boron steels suitable for control rods are normally cast because of forging difficulty, but it has been reported (1272) that a forgeable 4%B steel has been made by additions of 2-4% Si. With care this steel could be machined and welded.

PAPERS LISTED

190 Trudeau, L. P.; Effects of Neutron Irradiation on Mechanical Properties of Ferritic Steels and Irons.
1272 Hochmann, J., *et al.*; Les Aciers a Forte Teneur en Bore.
1978 Wilson, J. C.; Effects of Irradiation on the Structural Materials in Nuclear Power Reactors.

COMPATIBILITY

NIOBIUM, tantalum, zirconium and vanadium have been studied in CO_2 (1450) and in oxygen (704, 712). All of these metals show an initially slow uniform reaction rate followed after a more or less well-defined time by a superficial change in the oxide layer with a greatly increased rate of reaction. This breakaway phenomenon is a serious drawback to the use of these metals in a gas-cooled reactor. Extensive work is reported on alloying additions to these metals, particularly to zirconium. Although the general behaviour could not be greatly improved over unalloyed zirconium, additions of about 1 at.% copper, molybdenum or tungsten were successful in giving improved adherence of the scale and more reliable post-breakaway oxidation. The suggested limit of use for zirconium alloys in CO_2-cooled reactors is about 500°C (1450). The explanation of breakaway has been attributed to both the embrittling effect of dissolved oxygen in the substrate metal, as well as to a topographic change in the oxide layer itself.

Iron-aluminium alloys (707) have been shown to have good corrosion resistance, reasonable ductility and satisfactory high temperature strength, and it is suggested that they may compete with stainless and other alloy steels for high temperature use in oxidizing atmospheres.

A study has been made of the reactions of a number of uranium compounds with oxygen, nitrogen and water vapour (710). Compounds with silicon, carbon, aluminium, beryllium and boron were examined and in general rapid reactions were observed. In nitrogen, all the compounds with the exception of UB_4 reacted more rapidly with nitrogen than did uranium itself under similar conditions. With water vapour, reactions were somewhat slower than the corresponding reactions with oxygen.

Although Zircaloy is well established for use in high pressure water, aluminium alloys (194, 714, 766, 767, 1271)

show promise. It has been found that the addition of about 1% nickel or iron greatly improves the oxidation resistance of commercial aluminium in water up to 300°C, although in supercritical water vapour rapid disintegration may occur.

Beryllium is a possible canning material to replace magnesium. Unfortunately, it has been shown that uranium and beryllium are not compatible at 500°C (24); slight reaction was detected in a few days with the formation of the compound UBe_{13}. Surface films hinder but do not eliminate this interaction. A large number of metals were shown to react to some extent with beryllium, a notable exception being tungsten, which showed no interaction after six days at 700°C. The volatility of BeO in water vapour may be important below 1,000°C (1077).

There has been extensive research and development to determine the best choice of materials for use in both bismuth (270) and sodium (25, 2194).

A homogeneous reactor based upon a solution of 1,000 ppm uranium in bismuth is proposed (459) with the addition of traces of magnesium and zirconium as inhibitors. The favoured constructional material is 2¼% chrome, 1% molybdenum steel. It has now been shown conclusively (2173) that the mechanism of zirconium inhibition is caused by the formation of a protective film of Zr (N, C) which is produced by carbon and nitrogen diffusing out of the steel to react with adsorbed zirconium at the surface. In the absence of an inhibitor uranium nitrides are formed which are not as protective.

For use with U-Bi solutions, niobium is considered unsatisfactory at all temperatures, whilst beryllium is probably unsuitable above 700°C.

With this type of reactor a breeder blanket is also being developed (460) which will consist of a suspension of thorium bismuthide ($ThBi_2$) in liquid bismuth, the particle size being about 100 μ.

Apart from the sodium-graphite reactor (452, 705) already operating, a number of large power producing experimental reactors using sodium or NaK will be constructed during the next two or three years. The compatibility problems are now fairly well understood and certainly sufficient appears to have been done to enable a rational choice to be made for large-scale equipment. Unlike bismuth, corrosion in liquid sodium is extremely sensitive to the oxygen content of the liquid metal. A large number of materials of construction have been examined (25) in flowing sodium at temperatures up to 600°C and at oxygen levels from about 20 ppm down to about 1 ppm. Large amounts of dissolved oxygen can be brought to a reasonably low level of about 10 ppm by cooling to 150°C, when the excess oxide precipitates. Under these conditions both austenitic and ferritic steels are satisfactory. For possible canning materials, however, which include zirconium, niobium, tantalum, vanadium and beryllium (1091), these oxygen levels cause serious corrosion. The oxygen level may be further lowered by incorporating in the circuit powerful deoxidants such as solid zirconium or titanium in the form of thin foil heated to 600°C, or soluble materials such as calcium, magnesium or barium. With zirconium, for example (25, 703, 705), the corrosion of tantalum, niobium and vanadium is reduced to an acceptable level. Beryllium, however, still corrodes badly, although it is reported (1091) that acceptable corrosion rates may be obtained by the use of calcium in the liquid metal circuit.

Zirconium is used as a canning material in the sodium-graphite reactor (705). Strain-nucleated grain growth has been observed in liquid sodium which lowers the zirconium fatigue life. Hydride precipitation may occur at grain boundaries in zirconium when exposed to sodium containing traces of sodium hydride. Furthermore, this hydrogen can permeate the oxide layer on the metal.

It is stated (705) that molybdenum undergoes no weight or structure changes when exposed for long periods in sodium containing 10 ppm oxygen at 590°C.

For an advanced design of sodium reactor, development work (457) is being done on a slurry of UO_2 in the liquid metal, and it has been shown that 40 w/o of UO_2 can be pumped satisfactorily in a stainless-steel loop at 500°C. However, it is pointed out that this concentration would only be satisfactory for a thermal reactor design and further work is needed on more concentrated slurries essential for a fast reactor design.

There is great interest in the development of reactors using plutonium fuel (461, 2355). Molten plutonium alloys with magnesium and iron contained in thin-walled tantalum containers and cooled with liquid sodium are proposed (703). The compatibility of the plutonium alloys with tantalum depends strongly on traces of oxygen, hydrogen and nitrogen, and it has been found that the tantalum is significantly permeable to both hydrogen and oxygen, so that these gases must be maintained at the lowest possible levels in the surrounding liquid sodium. Hot trapping of the sodium with zirconium or tantalum has been found reasonably satisfactory.

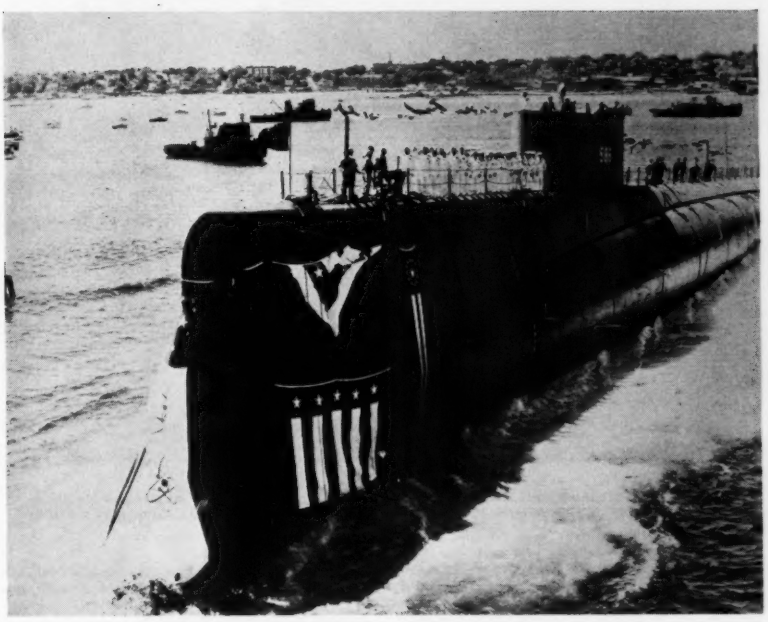
For use at much higher temperatures than are immediately envisaged, i.e. 1,000°C and above, some unusual liquid alloys, e.g. uranium-chromium eutectic have been investigated in yttrium containers (1032). Apparently satisfactory inert gas welding of this metal has been developed.

The use of molten salts as reactor coolants is now under consideration and one suggestion (605) for a homogeneous power reactor involves the use of UF_4 dissolved in a molten mixture of lithium fluoride and beryllium fluoride. These salt mixtures are very stable chemically and have been studied in loops of Ni-Cr and Ni-Mo alloys between 550°-900°C.

(*Translations on page* 442)

PAPERS LISTED

24 Baird, J. D., *et al.*; Compatibility of Beryllium with other metals used in reactors.
25 Davis, M., *et al.*; Compatibility of Reactor Materials in Flowing Sodium.
194 Krenz, F. H., *et al.*; Chalk River Experience with Zircaloy-2 and Aluminium-Nickel-Iron alloys in high temperature water.
270 Frost, B. R. H., *et al.*; Liquid Metal Fuel Technology.
452 Faris, F. E., *et al.*; Operating Experience with the Sodium Reactor Experiment.
457 Abraham, B. M., *et al.*; Fluid Metal Fuels: UO_2-NaK Slurry.
459 Isler, R. J., *et al.*; Engineering Experience at Brookhaven National Laboratory in handling uranium-bismuth reactor fuels.
460 (U.S.A.) The Thorium bismuthide breeder blanket.
461 Miles, F. T., *et al.*; Liquid Metal Fuel Reactor with Recycled Plutonium.
605 Macpherson, H. G., *et al.*; Molten Fluoride Power Reactor.
703 (U.S.A.) Materials compatibility in a molten plutonium fuelled reactor.
704 (U.S.A.) The Oxidation Characteristics of several reactor metals.
705 Carter, R. L., *et al.*; Recent Developments in the Technology of Sodium-graphite reactor materials.
707 Maxwell, W. A.; Iron-aluminium Base Alloys for Reactor Components.
710 Albrecht, W. M., *et al.*; Reactivity of Uranium compounds in several gaseous media.
712 Klopp, W. D., *et al.*; Effects of alloying on the Kinetics of oxidation of niobium.
714 Draley, J. E., *et al.*; High temperature aqueous corrosion of aluminium alloys.
766 Videm, K.; Studies on Corrosion of Aluminium in High Temperature Water.
767 Videm, K.; Corrosion of Aluminium with additions of Fe and Si in high-temperature water.
1032 Fisher, R. W., *et al.*; Feasibility studies on molten metal reactor components.
1077 Yosim, S. J., *et al.*; Corrosion Considerations of High Temperature Gas-cooled Reactors.
1091 Bett, F. L., *et al.*; The Compatibility of Beryllium with Liquid Sodium and NaK in Dynamic Systems.
1271 Coriou, H., *et al.*; Alliages d'aluminium contenant du fer et du nickel.
1450 O'Driscoll, W. G., *et al.*; The Oxidation of Groups IVA, VA and VIA Elements in Carbon Dioxide and the development of oxidation resistant zirconium alloys.
2173 (U.S.A.) Corrosion by a solution of uranium in bismuth (UBi).
2194 Lyashenko, V. S., *et al.*; On the corrosion of some materials in sodium and lithium.
2355 Williams, C., *et al.*; Liquid Metal Fuel Reactor and LMFRE-I.



Triton—the eighth U.S. nuclear submarine to be sanctioned—was launched at Groton, Connecticut, on August 19. Displacing 5,900 tons and 447 ft long, *Triton* is the world's largest submarine. She will be powered by two PWRs.

World News

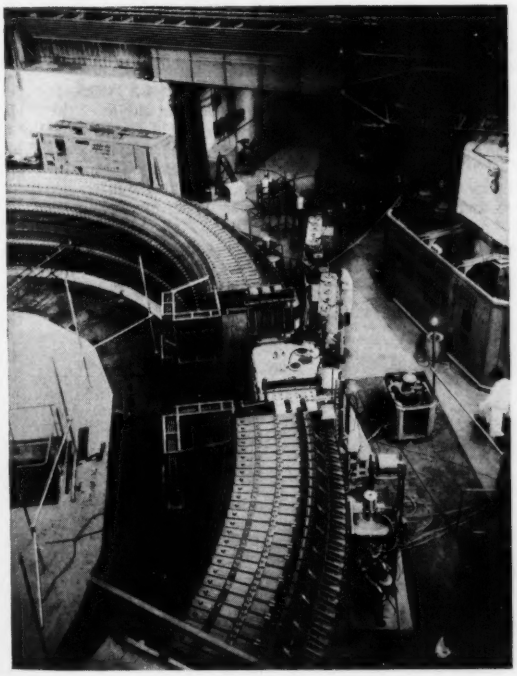
International

DECLASSIFICATION of U.S. and U.K. thermonuclear research was jointly announced by Mr. Lewis L. Strauss, chairman of the U.S. delegation, and Sir John Cockcroft, chairman of the U.K. delegation to the Second Atoms for Peace conference. Apart from improving the flow of information, the move will facilitate an interchange of personnel.

FELLOWSHIPS awarded by the International Atomic Energy Agency during its first year total more than 100. Candidates for a further 200 scholarships are being selected. Representatives from the 68 member states of the I.A.E.A. met on September 22 in the new permanent conference centre. This meeting place in the Neue Hofburg, one of the wings of the former Imperial Palace in Vienna, has been provided by the Austrian Government at a cost of over £700,000.

INSURANCE of marine and aircraft reactors has been discussed at two recent conferences. Mr. A. B. Stewart, of Lloyd's, presented a paper on the marine insurance aspect at the conference of the International Union of Marine Insurance at Salzburg early in September. The problem of insuring nuclear-powered aircraft was discussed at the annual meeting of the International Union of Aviation Insurers at Garmisch-Partenkirchen on September 12.

MEMBERS of the United States Joint Committee on Atomic Energy spent two days with the Euratom Commission in September. Object of the visit was to establish personal contact between the members of the committee and the commission and to examine certain practical details of the joint programme.



(Left) Saturne, a 1,100 ton synchro-cyclotron, the largest in Europe and fourth in the world, was commissioned at the French nuclear research establishment at Saclay on September 11.

(Right) The formal contract for the construction of a 200 MW nuclear power station at Latina, south of Rome, was signed on August 31 by Mr. A. J. Sayers, director and general manager, Nuclear Power Plant Co. and Ing. G. Martinoli, president, Societa Italiana Meridionale Energia Atomica.

EURATOM is considering sharing in the construction and operation of the U.K. high-temperature gas-cooled reactor project at Winfrith Heath. Presumably, any agreement to this effect would be in addition to support already promised by O.E.E.C. The six countries forming Euratom are all members of O.E.E.C.

COMMONWEALTH nuclear scientists from nine countries attended a six-day conference in the U.K. immediately after the Geneva conference closed. The conference opened at A.E.R.E., Harwell. Delegates met representatives of the Electricity Council and the C.E.G.B., visited Bradwell, Calder Hall and Dounreay and, on the last day, lunched

Commonwealth family portrait. During their six-day visit to this country the Commonwealth nuclear scientists lunched at Balmoral at the invitation of the Queen. Subsequently they posed for this photograph in the castle grounds.

with the Queen and the Duke of Edinburgh at Balmoral. The 37 delegates represented the following countries: Canada, Australia, New Zealand, Union of South Africa, India, Pakistan, Ceylon, Ghana and the Federation of Rhodesia and Nyasaland.

United Kingdom

CONSTRUCTION of two of the new nuclear power stations—Hinkley Point and Bradwell—has been hampered recently by strikes. At Berkeley, sparks from welding equipment set fire to a rubber pipe in a partly constructed reactor vessel. The fire was quickly extinguished.

SEA TRIALS to confirm the proposed technique of laying two cables simultaneously in a depth of 18 to 19 fathoms separated by not more than 10 ft are being undertaken by two British companies. The trials—in preparation for the laying of the cross-Channel d.c. submarine cable—are being undertaken by British Insulated Callender's Cables and Siemens Edison Swan.

FOUR HUNDRED FACTORIES are using radioactive isotopes and over 100 are operating X-ray apparatus in the U.K. according to the 1957 annual report of the Chief Inspector of Factories published recently. This report pays particular attention to the growing problem of radiation in industry and it mentions a survey undertaken by the radiological protection service in a luminizing shop: contamination varied from 40 to 150 m p.l. in various places. Although luminizing departments are covered by special regulations, there are still no statutory regulations governing the use of radioisotopes in industry: it is hoped, however, that a new code will be available before next year.

PERMUTIT has acquired world rights of a process for extracting uranium oxide from ore. The method is claimed to be cheaper than any other.

FACTORY for production of beryllium is to be built at Witton, Birmingham, by I.C.I.

Austria

NUCLEAR EXHIBIT of 1,000 sq ft was staged by the Board of Trade at the International Trade Fair in Vienna from September 7 to 14. Birmingham Exchange and Engineering Centre represented about 200 British companies.

Belgium

CONTRACT for 408 coils for the proton synchrotron at C.E.R.N., Geneva, has been placed with Ateliers de Constructions Electriques de Charleroi. The order is worth over $500,000.

Canada

URANIUM PRODUCERS in Canada must find world markets now to assure their competitive position when existing Government contracts finish in 1963, Mr. Harlow Wright, consulting engineer and managing director of Lorado Uranium Mines, told the annual conference of Provincial Mines Ministers at St. Andrews, New Brunswick. Mr. Wright went on to say that plans should be made now for a competitive floor price of possibly $6 per lb. "The fact that most producers have an assured market for all current production should not deter them from building up contracts for future sales."

PRODUCTION of uranium is now running at a rate of $300 million a year, having risen from $26 million in 1955. Sixteen Canadian companies are now in production: another two will start when financing problems have been solved. Nineteen mills and 25 mines are located in the Beaverlodge district of north Saskatchewan, the Blind River area of northern Ontario and around Bancroft in eastern Ontario.

Chile

URANIUM. National Society of Radioactive Materials has been set up by CORFO (the Chilean Development Corporation), the Caja de Credito y Fomento Minero, and the Empresa Nacional de Fundiciones to encourage private exploration for uranium and to provide a commercial basis for the sale of any uranium which may be discovered.

Cuba

ORDER for a 22 MW (E) boiling water power reactor, to be built at Santa Lucia, west of Havana, has been placed with Mitchell Engineering-A.M.F.-General Nuclear Engineering group.

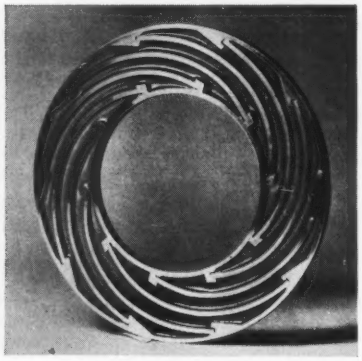
France

URANIUM EXTRACTION. The new plant at Narbonne will be in production early in 1959.

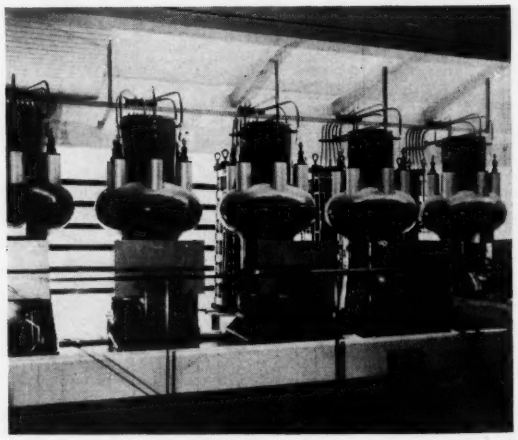
ELECTRICITE DE FRANCE is considering the construction of a nuclear power station in the Ardennes, with a capacity of 100 to 150 MW.

Germany

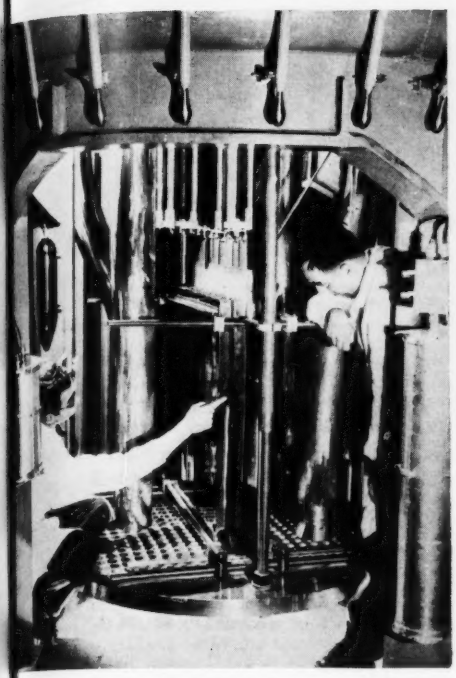
GLANDLESS CIRCULATORS for the heavy-water main coolant circuit of the MTR being built at Julich will be supplied by a British company, Hayward Tyler and Co., a member of the Platt group. An order for three such pumps was placed after the recent Atoms for Peace exhibition.

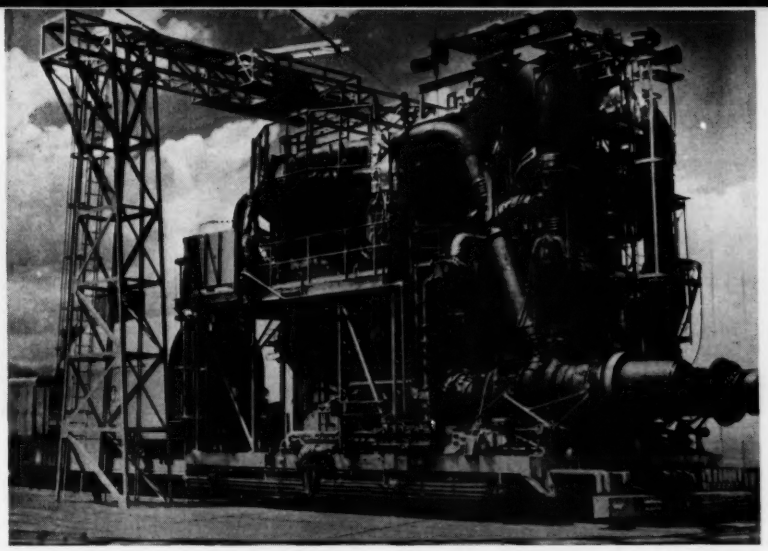


(Left) Section of one of the new fuel elements, recently inserted in DIDO at A.E.R.E., Harwell. Inner and outer tubes are impact - extruded aluminium with channel sections supporting U-Al sandwich plates. These are inserted, pinned temporarily, then dip-brazed. Four of these fuel elements have been installed: samples inserted in the element bore can be intensely irradiated.



(Right) Behind the scenes at Geneva. Some idea of the magnitude of the American scientific exhibit can be gauged from the fact that 3.2 MW of generating plant was required to power the various items of equipment demonstrated. Our photograph shows the battery of rectifiers handling this supply.





(Above) U.S. research into nuclear aircraft propulsion has involved construction of a reactor coupled to two aircraft turbo-jet engines at N.R.T.S., Idaho. Because of the radiation hazard it is mounted on two flat rail trucks and pushed to a deserted spot by a specially shielded locomotive.

(Left) A high-temperature research reactor for studying design data of the reactor cores for Triton's PWRs is being built at Knolls Atomic Power Laboratory.

Italy

ALTHOUGH there has been no official announcement of the award of a contract for the 150 MW SENN project, rumours at Geneva suggested that the American General Electric bid would be successful.

CONFINDUSTRIA (the Italian equivalent of the Federation of British Industries) has set up a committee to study problems concerning the peaceful uses of nuclear energy. The president of the committee is the Director of Edison Volta.

Japan

TECHNICAL TEAMS from the three British groups who have submitted tenders for Japan's first nuclear power station arrived in Japan during September. They will answer technical questions put to them by the Japan Atomic Power Co., the prospective purchasers of the 150 MW station.

NUCLEAR INCIDENT. The Nuclear research institute at Totaki Mura, north of Tokyo, was evacuated as a precaution when a natural uranium rod being cut on a lathe burst into flames. The fire was quickly put out. There were no casualties.

Mexico

AWAKENING INTEREST in nuclear matters has followed a visit of 11 scientists of the I.A.E.A. Recently Licenciado Gilberto Loyo, Mexican secretary for economic affairs, headed a delegation of 14 Mexican businessmen on a visit to Calder Hall; discussions took place with U.K. industrialists. On his return the Nuclear Energy Commission were instructed to accelerate investigations into uranium deposits in the State of Chihuahua.

Norway

RADIOACTIVE WATER overflowed from a tank in the underground station housing Norway's Halden boiling heavy-water reactor on September 6. The reactor itself was not in operation and the overflow occurred when water used to wash a filtering device was directed by mistake into tanks containing radioactive waste water from the reactor. Fortunately, the mishap was discovered in time to prevent the reactor control room being damaged.

Portuguese East Africa

RADIOACTIVE MINERALS. A new company has been formed to prospect for and market radioactive minerals in Mocambique. The new company, Companhia Uranio de Mocambique, is to have a subscribed capital of about £250,000; its headquarters will be in Beira.

Pakistan

ASSISTANCE. A three-man team from the International Atomic Energy Agency has spent a week in Karachi with the object of discussing Pakistan's atomic energy programme with the officials concerned, and drawing up recommendations on ways in which the I.A.E.A. can assist Pakistan.

Switzerland

CONTRACT for purchase of 11 tons of natural uranium fuel elements has been placed with Atomic Energy of Canada. The fuel will be used for a Swiss experimental reactor and for a sub-critical assembly.

Turkey

RESEARCH REACTOR is to be built near Ankara, according to Dr. Hasan Kursuneli, Turkey's delegate at the recent Atoms for Peace conference.

U.S.A.

DIVERSIFIED BUILDERS of California have received a contract for the construction and installation work on the second major building phase of the 62½ MW (T) 17½ MW (E) fast reactor EBR-2. Value of the contract is over $3½ million. Previous contracts on this project have totalled about $3 million and the overall budget for the plant is something over $29 million. Bids for the third major construction section of this reactor will be called for in early 1959.

BABCOCK AND WILCOX have been told by the A.E.C. that the Commission proposes to issue a permit for the construction of a low-power LMFRE alongside the nuclear merchant ship reactor critical experiment at the company's laboratory near Lynchburg.

NUCLEAR ENGINEERING of California have been licensed by the A.E.C. to dispose of radio-active material in increased quantities 25 miles off Point Reyes in the Pacific Ocean and 100 miles off New Jersey in the Atlantic at a minimum depth of 1,000 fathoms.

Meetings

September 30—Institution of Electrical Engineers (Cavendish Laboratory, Free School Lane, Cambridge). "The Use of Electronics in Nuclear Physics Research," H. V. Beck.

October 3—British Institution of Radio Engineers (North Glos. Technical College, Cheltenham). "Nuclear Instrumentation," D. G. A. Thomas.

October 7—Institute of Welding—Slough section (Lecture room, Community Centre, Farnham Road, Slough). "Test and Inspection of Welds," R. B. Whalley.

October 9—Institution of Electrical Engineers. Presidential Address, S. E. Goodall.

October 14—Institution of Electrical Engineers (Engineers' Club, Albert Square, Manchester). "Electrification of the U.K.A.E.A. Industrial Group Factories," J. W. Binns and W. J. Outram.

October 14—Society of Chemical Industry (Chemical Eng. Group). "Titanium and its Alloys as Materials of Construction for Chemical Plant," Dr. K. W. J. Bowen.

October 27—Institution of Electrical Engineers (James Watt Memorial Institute, Birmingham). "Sceptre Design and Experiment," R. F. Hemmings.

October 27—Institution of Electrical Engineers (Cavendish Laboratory, Cambridge). "Operational Experience at Calder Hall," K. L. Stretch.

October 28—Institution of Electrical Engineers (Engineers' Club, Manchester). "Digital Computing Machines," T. Kilburn.

October 28—Institution of Mechanical Engineers (in conjunction with the Aluminium Development Assn.). Symposium on Aluminium Pressure Vessels.

Personal

Mr. D. W. Fry.

Mr. R. D. Vaughan.

Mr. B. M. Adkins.

Mr. G. Campbell.

Appointments

Mr. D. W. Fry, deputy director of A.E.R.E., as director of the U.K.A.E.A. establishment at Winfrith Heath. The freedom of Weymouth has also been conferred upon him.

Hawker Siddeley have integrated the constituent members of the Brush group more closely within the framework of the parent company. The Board of Brush has been dispersed. All the directors with the exception of **Sir Roy Dobson, Mr. J. F. Robertson** and **Mr. P. C. Sharp** have resigned. **Mr. G. C. R. Eley,** former Brush chairman, remains a director of Hawker Siddeley. **Mr. A. H. Frampton** has been temporarily appointed with executive responsibility for Brush Electrical and Fuller Electric. **Sir George Briggs** will control the Brush Diesel engine companies. **Mr. D. S. A. E. Jessop** (personnel director), **Mr. C. F. Barnard** (heavy engine division) **Mr. Michael Clear** (export sales) and **Mr. J. Calderwood** (technical director) although ceasing to be directors, will continue to act in their respective capacities.

Mr. R. D. Vaughan, chief engineer of The Nuclear Power Plant Company as a director.

Commander H. Pasley-Taylor, joint general manager, as a director of Elliott Bros. (London).

Mr. B. M. Adkins, publicity manager of Elliott Automation, as public relations and information officer to the European Nuclear Energy Agency, a department of the O.E.E.C., in Paris.

Following a re-grouping of departments to form a new engineering division at Whessoe, these appointments have been made: **Mr. R. F. Bishop,** manager; **Mr. D. S. Hudspeth,** chief storage engineer, **Mr. R. W. Horseman,** chief engineer pressure vessels; **Mr. J. Thompson,** chief chemical engineer.

Mr. G. Campbell as general manager of the chemical and metallurgical division of The Plessey Company.

Mr. R. F. Bishop.

Mr. S. H. Griffiths.

Dr. Albert V. Crewe as director of the particle accelerator division, Argonne National Laboratory.

Mr. William H. McFadzean, chairman and managing director, B.I.C.C., as deputy president of the Federation of British Industries.

Mr. G. B. Taylor as sales manager (works division), and **Mr. R. H. Foster** as works manager of Ashmore, Benson, Pease and Company.

Mr. W. G. Pinder, managing director of Crossley-Premier Engines, as a director of the parent company, Crossley Bros. **Mr. Hugh Beck,** director, and **Mr. John Ivor Pugh** secretary and accountant of Crossley Bros., as directors of Crossley-Premier. **Mr. John Shie's** as secretary and chief accountant of Crossley-Premier.

Mr. S. H. Griffiths, head of the John Thompson group research laboratories as a director of John Thompson (Wolverhampton).

Mr. O. S. Smith, director of the division of organization and personnel as director, Office of Industrial Relations of the U.S.A.E.C. in Washington. **Mr. A. L. Tackman** as director, Office of Personnel.

Mr. R. Yeoman as general manager of foundries owned by James Hodgkinson (Salford).

Mr. T. P. W. Norris as deputy chairman of George Kent, also **Mr. W. A. Hartop** as managing director. **Mr. R. E. Handford,** deputy managing director, who relinquishes his executive functions retains his seat on the Board. **Commander P. W. Kent,** formerly chairman and managing director, remains as chairman. **Mr. W. G. Ardley** and **Mr. L. H. Kent,** directors, are retiring.

Sir Alexander Fleck as chairman of the scientific advisory council to the Minister of Power.

Mr. Bernard A. Christie as home sales manager of Coventry Climax Engines following the untimely death of **Mr. John M. Morris.**

Mr. W. Eric Ward, works production manager, as general manager and director of Consett Iron.

Mr. G. Morris as foundry works manager, Head Wrightson Iron Foundries, a subsidiary of Head Wrightson and Co.

Mr. Trevor-Jones as sales director of M. and W. Grazebrook. **Mr. A. C. Brooks** is retiring due to health reasons but remains a director and consultant.

Mr. C. J. Brous, as assistant chief of engineering, Atomics International, a division of North American Aviation, Inc.

Retirements

Mr. A. L. Napier, a director of John Thompson Water Tube Boilers since 1930, has retired.

Mr. Edwin W. Ganderton has retired from the Board of Powell Duffryn.

Mr. J. C. Mitchell controller of N.E. division C.E.G.B. retires on September 30.

Mr. W. L. Baker, manager of the metal finishing division of The Pyrene Co., has retired. He will be succeeded by **Mr. H. A. Holden.**

Tours

Mr. Basil W. Balls, technical sales manager of Foxboro-Yoxall, has been visiting the American company for a fortnight for discussions on new products.

Awards

Dr. Johannes Frischauf, of Vienna, the first to take up an I.A.E.A. scholarship in the U.K., is to study the use of radioactive isotopes in medicine at A.E.R.E., Harwell.

Obituary

Nuclear Engineering records, with regret, the deaths of the following personalities:—

Dr. Ernest Lawrence, American inventor of the cyclotron, has died at Palo Alto, California. He was 57. In 1939 he was awarded a Nobel prize for physics; eighteen years later he received an Enrico Fermi award.

Professor Friedrich Adolf Paneth, director of the Max-Planck Institute for Chemistry, has died at the age of 71. He was one of the first to realize the value of radioactive materials as tracers.

Mr. Harry S. Broom, founder, chairman and joint managing director of Broom and Wade, died on September 12. He was 84.

Mr. R. M. Laid, for more than 35 years a director of W. Crockatt and Sons.

Sir Frederick Yapp, chairman of Vickers-Armstrongs from 1944 to 1946, died on September 5 at the age of 78.

Mr. Frederick Osgood Hickling, technical manager of Ransome and Marles Bearing Company.

Mr. Samuel Thomson, a director of Colvilles and general manager of Dalziel and Lanarkshire Steelworks.

Industrial Notes

An Anglo-Dutch Trade Council has been set up to further the promotion of British trade with Holland. The address of the Council is 99 Jan van Nassaustraat, The Hague, Holland.

The Hawker Siddeley Group has announced that the Brush Group is to be completely integrated with the main company. The move is represented as an inevitable part of the rationalization programme of Hawker Siddeley and does not indicate that the Brush factories will not continue to operate and sell their own products under their own name. Several managerial changes have resulted.

The Power Gas Corporation, John Thompson, and Humphreys and Glasgow, have formed a new company called Nuclear Chemical Plant, Ltd. This company will pool the knowledge gained by the three companies in the design and engineering of process and treatment plant for the nuclear industry.

I.C.I. Metals Division is to establish what is believed to be the first plant in Europe for the production of wrought beryllium. The plant is designed to produce semi-fabricated forms of the metal, such as rod, tube and plate and finished machine parts. The metal will be received into the factory as flake or small beads and melted under vacuum in induction furnaces to produce an ingot. The ingot is then powdered and fabricated into the required shapes by sintering compacted powder under vacuum. Initial output of the plant has been earmarked by the A.E.A.I.G. as canning material for fuel elements in the AGR. The cost of the plant has been quoted as between £1¼ and £3 million with an output of up to 15,000 lb/an.

Whessoe have been awarded the contract for the pressure vessel for AGR. The vessel is a vertical cylinder approx. 21-ft dia. with hemispherical top and bottom heads; the overall height is 53½ ft. The vessel is designed so that the top head can be completely removed for changing the graphite core and in addition it is perforated by a large number of closely pitched charge tubes and control rod stand pipes. The contract also includes provision of the core and moderator support, internal baffles and the internal shell.

English Electric are to make the 33 MW steam turbo-alternator set, condensing and feed heating plants with auxiliary equipment for AGR. The turbine is a 2-cylinder impulse reaction type and will be designed for steam at 650 p.s.i.g. at a temperature of 850°F. The unit is of standard design, 70 similar sets already being in service. Commercial stations based on this reactor concept are expected to give a thermal efficiency of 32%.

20th Century Electronics have signed a 10-year agreement with the Atomic Energy Authority for the manufacture and supply of boron-10. The company has been operating a number of columns for the past few years but the new contract provides for the transfer of the low temperature distillation plant from Capenhurst to the Surrey factory where the two columns will be hung from a steel pylon. The columns, 75-ft long and weighing 4 tons were transferred and re-erected in less than 10 days.

Westinghouse Electric International have extended their coverage of European markets by establishing in Geneva a subsidiary—Westinghouse International Atomic Power Company.

Wild-Barfield Electric Furnaces, of Watford have received an order from the A.E.A.I.G. for two 100-lb. arc melting vacuum furnaces of the cold mould type which will be used for consumable and non-consumable melting. Based on the NRC model 2721, each equipment has its own pumping system but with a common power supply. Four-inch ingots can be melted in each furnace with a 50% reserve of power or, alternatively a 6-in. ingot can be melted in one furnace with a similar power reserve.

Tube Products have developed and put into operation at the Company's Falcon Works, at Wednesfield, a new electric resistance weld tube mill. The mill can produce ERW steel tubes up to 5½ in. in diameter with a wall thickness of ¼ in. in lengths up to 60 ft. The mill is accommodated in two new bays of 77,000 sq ft area built on to the existing factory.

Taylor Woodrow are now occupying the new four-storey extension to their headquarters at Southall. The extension, 132 ft long, has an overall superficial floor area of approximately 40,000 sq ft.

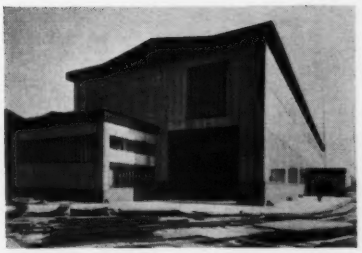
Electronic Associates, European Division, have recently supplied to A.E.R.E. a large general purpose type 231R " Pace " analogue computer. Priced around £90,000 the computer is a high accuracy machine with linear and non-linear computing components, modular patch panel and Adios system which allows the computer to be programmed by paper tape or electric typewriter. This is the 17th " Pace " machine to be sold in Europe in the past 12 months. A similar machine is already installed at Saclay.

Sunvic Controls have recently opened a training school at their Harlow factory, to instruct customers, operators and maintenance staff in the use of Sunvic's pneumatic and electronic controlling instruments.

The Plessey Co., recognizing the difficulty of obtaining small quantities of components for development and experimental work in laboratories, has initiated a new scheme known as the " Blue Arrow " service aimed at giving express delivery. Full details of the new service can be obtained from the Sales Manager, Electrical Connectors Div., The Plessey Co., Ltd., Cheney Manor, Swindon, Wilts.

Birlec announce that a Johannesburg branch office under the management of Mr. S. G. King has now been formed. The new branch will deal with all enquiries including project design and engineering service work. Address of the new office is P.O. Box 99, Witfield, Transvaal.

The company has recently completed the installation of a gas-fired roller hearth annealing furnace in the new stainless steel mill of **Talbot Stead Tube, Ltd.** The furnace, which can turn out 1 ton of steel per hour, is remotely controlled from 3 control desks supplied by **Teledictor,** and in the new electronic control system, considerable use has been made of Warner Electro-magnetic brakes and clutches, made by **Westool.** The



First bay of a new heavy fabricating shop at Head, Wrightson's Thornaby Works.

mill will be used for the production of the very large quantities of tube needed for burst slug detection gear in the commercial nuclear power stations.

Chloride Batteries are to supply two massive stand-by batteries each weighing over 120 tons for the Berkeley Nuclear Power Station. The two batteries are of the 118 FF W 22 open-top Plante 45-plate type, in lead-lined wood boxes, with capacities of 4,400 Ah.

High Voltage Engineering have supplied a Van de Graaf accelerator for use in food irradiation studies. The machine has been bought by the Technical University at Karlsruhe and is capable of delivering a high-beam current at 1 MeV. The company is also to supply a 6 MeV accelerator to the University of Zurich and a 3 MeV machine to the University of Neuchatel.

George Kent's mobile exhibition recently set off on a three-months' tour of Sweden, Norway, Denmark and Poland showing latest industrial instrumentation.

Plannair's range of air movement equipment does not include (as we reported last month) climatic test chambers and high- and low-temperature cabinets. These units, installed in the company's new laboratories at Leatherhead, will be used solely for testing Plannair products.

Plessey Nucleonics inform us that performance data quoted for their range of neutron detectors was reproduced by permission of A.E.R.E.

Address Changes

Rhodes Brydon and Youatt, makers of " Mopumps," have opened a Midlands office at Griffin House, Ludgate Hill, Birmingham, 3. Telephone Cen 8911/2.

Elcontrol, Ltd., have transferred all their London departments to their works at Wilbury Way, Hitchin, Herts.

Kelvin and Hughes have transferred their executive offices from London to Wembley. The new address is Empire Way, Wembley, Middlesex. Telephone Wembley 8888.

British Arca Regulators will move to Sisson Road, Gloucester, on October 6, from their London offices. These premises will comprise manufacturing space for light engineering products and all administrative offices.

B. and K. Laboratories have just opened a new showroom in the West End of London at 4 Tilney Street, Park Lane, W.1. The company has, for a number of years, acted as sales and service agents for a wide range of American and Continental electronic equipment.

K.D.G. Instruments have opened a London sales and service office and showroom at 100 Fleet Street, E.C.4.

L

Geneva Personalities

(1). Sir Edwin Plowden (Chairman U.K.A.E.A.) and Mr. Louis Strauss (Chairman U.S. delegation).

(3). Sir John Cockcroft with Dr. John Wilcox (University of California, Radiation Labs.), and Dr. Van Atta (Director of the Sherwood Project at U.C.R.L.).

(2). Professor Paul Scherrer (President of the Swiss Governmental Commission on Atomic Power), with members of the English Electric-Babcock and Wilcox-Taylor Woodrow atomic power group.

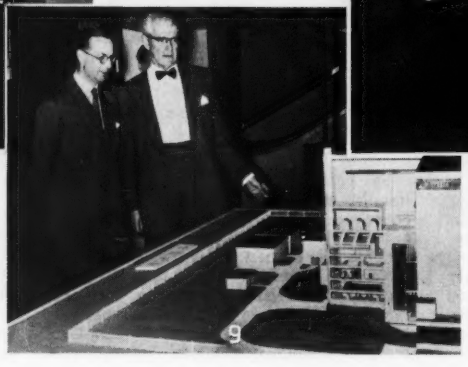
(4). M. Thomas Holenstein (President of the Swiss Confederation) and Mr. M. L. Whitehouse (N.E.T.A.C.).

(6). Sir Leonard Owen (left) and Mr. J. C. C. Stewart (Industrial Group, U.K.A.E.A.).

(5). Mr. Dag Hammerskjold (U.N. Secretary-General) (centre) and (right) Prof. Francis Perrin (President of the Conference).

(7). M. Dussoix (President, Geneva Town Council) (centre). On the left is M. Dutiot (President Exhibition Committee).

(9). Lord Coleraine (Chairman Atomic Power Constructions, Ltd.) and Sir Edwin Plowden.



(8). L–R Mr. P. Warren (Commercial Manager, U.K.A.E.A.), Mr. B. R. Sankey (Managing Director, International G.E.), Dr. Brady (U.S.A.E.C.) and Sir Edwin Plowden.

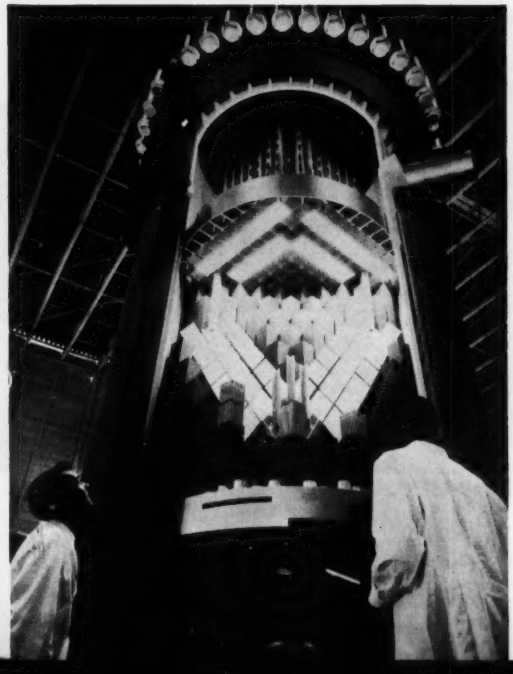
Science and Industry at Geneva

The Exhibitions in Retrospect

THERE is no doubt that both the scientific and the commercial exhibitions held in conjunction with the second Atoms for Peace conference in Geneva were extremely successful. The scientific exhibition—housed in a specially erected building in the Palais des Nations grounds—was seen by more than 100,000 people. Even though some countries' exhibits were disappointing the overall picture was characteristic of the immense scientific progress already achieved in the application of nuclear energy

On the commercial side the volume of visitors—although as impressive as the figure for the scientific exhibition—does not give a real indication of the importance of the exhibition. There were, however, many valuable inquiries, some extremely large orders were finalized, and the lively tone of the exhibition was in keeping with the world's rapidly expanding capacity for the production of equipment for all nuclear requirements. In sharp contrast with the much smaller 1955 exhibition in Geneva exhibitors this time were more interested in selling actual hardware rather than discussing the possibility of making it.

Whether there is any justification for two separate exhibitions in halls three miles apart in a busy, crowded city is a subject that must be more seriously considered in the future. Any attempt to artificially separate science from industrial enterprise in nuclear engineering must inevitably retard the establishment of the world's nuclear industry on a sound commercial basis.



(Top of page) Facing each other across the aisle at the commercial exhibition in the Palais des Expositions were the U.K. and the U.S. sections. Other European countries—principally France, Switzerland and Germany—were represented in the hall at the end of the aisle.

(Left) The U.S. scientific stand was dominated by a full-scale model of the 38-ft.-high Shippingport pressure vessel and core.

THE SCIENTIFIC EXHIBITION

U.S.A.

Of the exhibitions themselves, the scientific display was completely dominated by one country, the U.S.A. Within a ground floor area of some 36,000 sq. ft. every facet of the tremendous U.S. atoms-for-peace programme was presented in a seemingly never-ending panorama of beautifully conceived displays. In spite of the broad coverage and the exceptional amount of detailed information released the exhibits were ingeniously interrelated so that the story was unfolded stage by stage according to the visitor's interest.

On the ground floor the U.S. exhibit comprised four sections: basic sciences, life sciences, fission reactors and fusion research. These sections were overlooked by a mezzanine floor containing a

technical information centre with four pocket cinemas, a lounge for delegates and a technical information library.

Highlights of the basic sciences section comprised displays of some of the exciting new developments in nuclear physics and chemistry, including the recently discovered catalytic action of the mu-meson in deuterium fusion, the production and indentification of anti-nucleons, neutrino physics and the failure of the conservation of parity in certain kinds of sub-atomic reactions. Perhaps one of the most remarkable exhibits was the technical achievement of demonstrating the striking differences between liquid helium 3 and liquid helium 4. To do this it was necessary to maintain a helium 3 reservoir near 0.6°K by constant pumping and immersion in a conventional helium 4 cryostat operating at about 1.1°K.

In the life sciences group a popular feature was a large liquid scintillation counter, arranged to measure the radioactive body content of visitors. As might be expected the use of radioisotopes in research, diagnosis and treatment of cancer, heart disease and other medical problems was given full coverage. Other displays of general interest included studies of such basic life processes as photosynthesis, the biodynamics of metabolism, enzyne action and milk production. Seven isotope laboratories were shown in operation.

Dominated by a most realistic full-scale model of the Shippingport reactor, the fission section was typical of the immense U.S. programme of research and development on all types of reactor. Naturally, great interest was shown in both of the research reactors which were in operation during the conference.

The first of these, TRIGA, developed by General Atomics, was actually producing short lived radioisotopes for use in other parts of the scientific exhibit. TRIGA, rated at 10 to 30 kW, has been expressly designed as an inherently safe training research and isotope production reactor. The fuel elements are made from a hydrided solid homogeneous alloy of 20% enriched uranium and zirconium.

Rivalling TRIGA was the 10kW ARGONAUT which was actually assembled, tested and put into operation during the conference. Developed by Argone National Laboratory, ARGONAUT is water moderated with a graphite reflector. The core consists of plate-type fuel elements arranged in annular geometry. A graphite column within the fuel ring provides facilities for exponential or irradiation experiments. The necessary shielding is obtained by interlocking concrete blocks.

So far as power reactors were concerned, exhibits in this section described the Shippingport reactor which became critical last December and the work in progress on the development of a second core which is expected to increase the electrical output from 60 MW to 100 MW. Other power reactor projects described included the 151 MW Indian Point station, the 135 MW Yankee Atomic unit at Rowe, Massachusetts, the 180 MW Dresden plant and the 100 MW Enrico Fermi power breeder project at Lagoona Beach, Michigan. On the experimental side of the U.S. programme reactors included the 5 MW(E) EBWR, the experimental breeder No 2, the SRE and OMRE, ETR, and homogeneous reactor experiment No. 2. Maritime applications of nuclear energy were represented by a model of the *N.S. Savannah*.

The DCX device by Oak Ridge showing thearc and the injection of a beam of molecular ions.

In spite of the excellent presentation and the wealth of information made available the first three sections of the U.S. exhibit paled into insignificance compared with the section devoted to fusion research. Never before have so many experimental pieces of fusion apparatus been shown in operation together.

Fusion research in America is largely handled by four research centres: Princeton University, University of California, Oak Ridge National Laboratory and Los Almos Scientific Laboratory. Each contributed to the fusion exhibit.

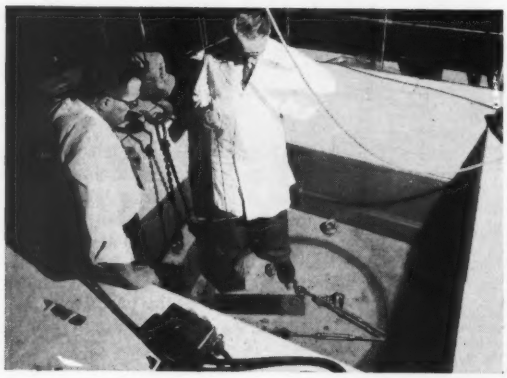
Princeton, for example, demonstrated the stellarator approach. Four aspects of the controlled fusion problem were emphasized: confinement of the ionized gas; stability of this confinement; heating of the gas and control of impurities which would cool the gas. Of the two demonstration models one tube was in the form of a racetrack, the other in the shape of a figure 8.

Next, the University of California exhibit, where the display was concerned with three basic approaches to the problem of heating and containing a plasma. These approaches were the pinch, the magnetic mirror machine and the Astron. By means of a fast electronic viewer visitors could see the development of a helium discharge lasting 10 microsec. A homopolar motorgenerator with a "flywheel" of ionized gas held together by a magnetic field was shown in operation, the energy stored in rotation being observed as a large current pulse when the terminals were short circuited.

Oak Ridge's contribution was the direct current experiment—DCX. The unit comprised a metal enclosure 3 metres long and 1.5 metres square. Through a side window visitors could see a glowing ring of high-speed deuteron particles 20 cm in diameter. From the top of the enclosure molecular ions composed of two deuterons and one neutron were shot inward from an ion source. The circular path of the atomic ions produced when the beam entered the arc was made visible by introducing carbon particles which became incandescent.

Finally, in the fusion section Los Almos Laboratory featured experiments with the Perhapsatron S-4 which has been devised to study pinched discharges in a toroidal discharge tube. Los Almos is also responsible for pinch research using linear tubes: these are known as the Columbus devices. Counters showed neutron production during the pulses.

The U.S. technical information centre was extremely well organized. Visitors were able to look through a library of some 350 books and journals, consult a microcard index, or see on request any one of 27 films on various aspects of nuclear developments in the U.S.



(Left) Dr. David Lennox and Dr. Allen B. Smith of Argone National Laboratory inserting a fuel element into the 10 kW ARGONAUT.

(Right) The U.S. technical information centre was kept busy throughout the exhibition.

(Left) General Atomic's 10 kW TRIGA research reactor was operated during the whole of the exhibition to provide short lived radioisotopes.

(Right) Mr. Lewis Strauss, past chairman of the U.S.A.E.C., brought the 10 kW ARGONAUT to criticality towards the end of the exhibition.

United Kingdom

Although obviously overshadowed by the sheer size of the U.S.A. exhibit the U.K. scientific stand was, nonetheless, the best yet in the series of exhibitions at which the U.K.A.E.A. has been represented. Basically the U.K. display was concerned with three subjects: (a) the evolution of the British power and research reactor programme and its future (b) controlled thermo-nuclear reactions (c) current research activities of the Authority and British industry.

Quite naturally the first subject was essentially concerned with the steps that led up to the construction of Calder Hall and the first four commercial stations. The future programme of the Authority, the advanced gas-cooled reactor (AGR) using a ceramic fuel and alternatively a gas-cooled heavy water moderated type GCHWR were described on display panels. The projected reactor for the 1970's the high temperature gas cooled (HTGCR) was also covered and the exhibit featured a model of the 10 MW HTGCR which is to be constructed at Winfrith Heath.

On the thermo-nuclear side, following an introductory section outlining the early development of the pinch effect in the U.K. and subsequent experiments, visitors could see a detailed ⅓ scale model of ZETA. Other exhibits included a Mk. I torus and part of the Mk. III torus, together with photographs and diagrams of the ZETA control room. Thermo-nuclear research at Aldermaston Court by Associated Electrical Industries was also described, a feature being the inclusion of a model of Sceptre III.

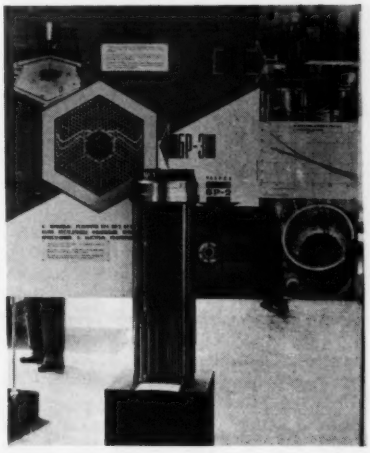
Finally, there was a working exhibit showing work being carried out at A.W.R.E., Aldermaston on high current gas discharges. The device demonstrated, MINNIE, comprised a low inductance condenser bank assembly producing a pinched discharge with neutron production. Excellent results have been obtained with MAGGI, a 45 kJ version of MINNIE.

The remainder of the U.K. stand was concerned with technology supporting the reactor programme, chemistry, pure research and health and safety aspects.

U.S.S.R.

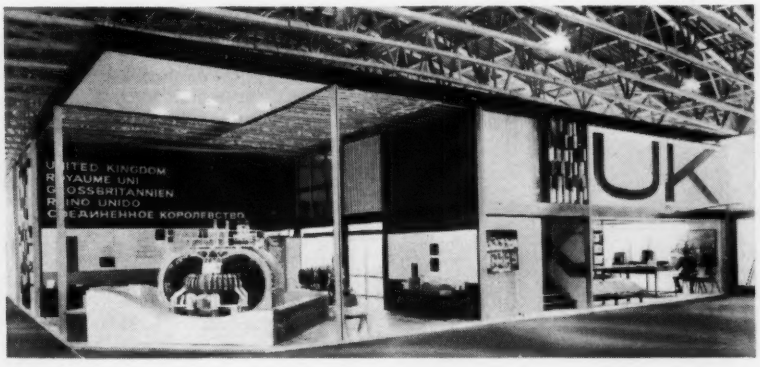
The U.S.S.R. display certainly did not achieve the high standard of presentation established by the U.S.A. and the U.K. Although many of the models shown were beautifully executed, the display panels gave the impression that they had been prepared in a hurry by junior students. It was difficult too—apart from sheer propaganda purposes—to find sufficient justification for the inclusion of a full-scale Sputnik 3 (albeit that it was equipped with instruments for measuring cosmic radiation) in a display solely concerned with nuclear energy.

There is no denying, however, that the Soviet Union has made considerable progress in developing peaceful applications of atomic energy and that great importance is attached to international collaboration in this respect. As the display panels illustrated, research reactors have already been supplied to China, Rumania, Poland, East Germany and Czechoslovakia. The Soviet is also

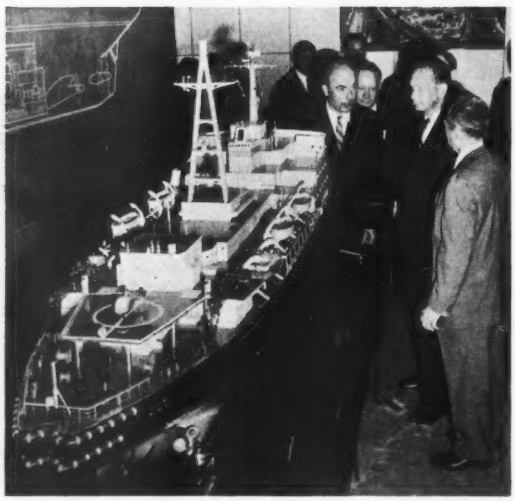


Display panel describing the series of Soviet fast breeder reactors. Core of the BR-5 which went dry critical in July (shown in foreground) is rated at 5 MW(T); fuel elements are Pu in stainless steel cans.

supplying equipment for the construction of experimental reactors in Yugoslavia and Egypt. Three types of reactor were represented on the stand: a 1-1.7 MW water moderated and cooled, a 2 MW water moderated and cooled and a 6-10 MW heavy water moderated. The Soviet's most important contribution in the field of international collaboration is, of course, the Joint Institute for Nuclear Research (JINR) at Dubna and the exhibit included a large photograph of the 10 MeV synchro-phasotron electromagnet in the high energy laboratory there. A number of items of electronic equipment developed for use at JINR were also displayed. These units included



A fine 1/3 scale model of ZETA occupied a prominent position on the United Kingdom stand in the scientific exhibition.



Among the visitors to the Soviet section of the Scientific display was Mr. Dag Hammarskjöld (second from right) Secretary-General of United Nations. He was shown this model of "Lenin," the nuclear icebreaker by the Soviet exhibition manager, Mr. Kalinin.

a 100-channel amplitude analyser with a ferrite torus memory intended for obtaining amplitude spectra of pulses and an electronic computer for measuring energy mass and other parameters of nuclear particles registered in photoemulsions. Recent work in the Soviet Union has been concerned with the preparation of backless photographic emulsion layers of up to 600 microns thick for use in physical investigations of nuclear reactions.

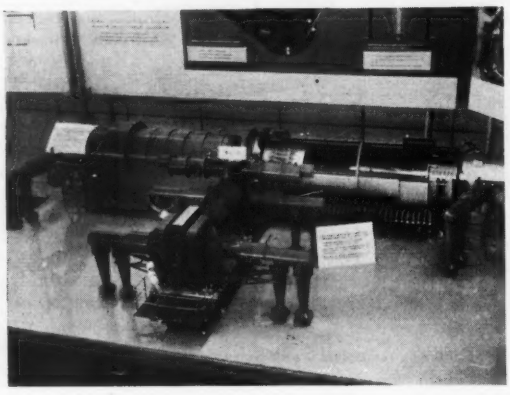
Examples of Soviet contributions to the development of thermonuclear energy were mainly in model form: an apparatus with a toroidal chamber and magnetic traps of different types; also the d.c. OGRA, the full-size version of which has a vacuum chamber of 1.4 metres diameter and 20 metres long. A Soviet torus, ALPHA, was photographically depicted.

The Soviet nuclear power programme is broadly based and the display panels described the various types of reactors in course of construction. At Voronezh, for example, a 420 MW station with two pressurized water reactors is being constructed whilst a 400 MW station in the Urals will be based on the first Soviet 5 MW power reactor arranged for high-temperature operation. A 50 MW fast reactor is being built on the Volga and a 50 MW reactor using sodium as a coolant is being studied. The marine applications of nuclear energy were represented by a scale model of the nuclear ice-breaker *Lenin*, which is due to be launched shortly.

The remainder of the Soviet exhibit spotlighted some of the many side aspects of the development of nuclear energy from mining to metallurgical research, biological applications of isotopes and isotope production.

Czechoslovakia

This Iron Curtain country provided one of the surprises of the scientific exhibition with details of its projected 150 MW(E) heterogeneous nuclear power station. Sitework has already begun at Bratislava near the southern border. A wall panel on the stand gave the following particulars: Fuel, natural uranium in magnesium/beryllium cans; operating temperature, 500°C; CO_2 cooling at 60 atmospheres with inlet 125°C and outlet 425°C; pressure vessel 19 metres high, 5 metres diameter with a wall thickness of 140 mm; six centrifugal blowers; dual pressure heat exchangers with forced circulation; three 50 MW turbines each with a h.p. stage at 29 atmos, 400°C and l.p. stage at 2 atmos, 180°C.



The Soviet section also contained this model of the OGRA, the Russian version of DCX.

A feature of the stand was a section of a weld in 140 mm mild steel, and it was explained that the circumferential rings forming the pressure vessel will be welded on site. Other Czech exhibits included several groups of electronic instruments suitable for nuclear applications. It would appear that Czech factories have ample capacity and the technical knowledge necessary to construct the country's first nuclear power station from indigenous resources. It is understood, however, that the design of the fuel element is Russian.

France

Another interesting stand in the scientific section was the French exhibit where again some of the emphasis was on thermonuclear research. The display included a pinched ring discharge in xenon and photographs of the TA 2000. A section of the liner of this machine was shown: the aluminium torus is 2,000 mm in diameter and it has been developed for the study of stabilized annular discharges. Other exhibits were concerned with the development of fuel elements for France's nuclear programme and details of the G.2 and G.3 piles and the high flux research pile, EL.3, with a model showing the different experimental facilities available. One of the most surprising French exhibits was a gaseous diffusion membrane.

Canada

Although Canada's display in the scientific exhibition was mainly concerned with publicizing the country's expanding uranium mining industry and the availability of isotopes for medical and industrial applications, part of the exhibit described the nuclear power programme. In course of construction Canada has a 20 MW (E) station known as NPD which will serve as the prototype of the projected 200 MW NPD-2. Canada is also collaborating with India in the construction of a 40 MW NRX type research and test reactor at Trombay.

Venezuela

Although small, Venezuela's exhibit was built around a beautifully executed model of the research establishment in course of construction near Caracas. RV-1, the first Venezuelan reactor, is a 3 to 5 MW swimming pool type scheduled for completion in August, 1959. Located 14 km south west of Caracas at Altos de Pipe, RV-1 has been designed by General Nuclear Engineering Corporation in conjunction with General Electric; Shaw Metz and Dolio have acted as architects-engineers. RV-1 will use 20% enriched uranium as fuel in MTR type elements.

Argentina

Argentina's stand in the scientific exhibition was designed to present a glimpse of current developments leading to the establishment of nuclear research facilities in the country. In the commercial exhibition another Argentinian stand contained a model of an R.A.2 training and research reactor.

South Africa

The South African feature, although excellently presented, was disappointing. The stand included a large World map showing the principal uranium deposits but no effort was made to describe in detail methods of mining or extraction processes evolved in the Union. It was surprising, too, considering South Africa's expanding production of uranium that no effort was made to " sell " it on an international basis.

India

A large model of the Trombay Atomic Energy Establishment near Bombay was the principal feature of the Indian stand. The varied aspects of work at Trombay were illustrated by a number of photographs. At Alwaye, near Cochin, the Indian A.E.C. has established a plant to separate thorium from monazite sand. The thorium produced in this way is handled in a factory at Trombay operated by Indian Rare Earths, a private limited company. A considerable proportion of the output is exported.

Scandinavia

The close co-operation existing between the Scandinavian countries in nuclear research and development was demonstrated by a joint exhibit featuring the contribution that each country has already made. Norway, for example, operates a joint establishment JENER together with the Netherlands. The centre makes use of an experimental reactor known as JEEP, a model of which was included on the stand. Another model featured the Halden boiling heavy water reactor (HBWR) designed by JENER and built by Norway's Institutt for Atomenergi. The HBWR is expected to go into operation shortly.

The Danish section of the exhibit contained several models of the reactors in operation or in course of construction at Risö. The first of these, DR1, is a low-energy homogeneous type for educational purposes and physical experiments. DR2, which is being constructed, is a water-moderated heterogeneous tank-type research unit with facilities for neutron exposure experiments and isotope production. The third unit is a PLUTO-type heavy-water moderated high-flux reactor.

The third member of the Scandinavian group at the exhibition was Sweden and attention was concentrated on the country's nuclear power programme. Sweden has had an experimental natural uranium, heavy-water reactor in operation since 1954. Two power reactors are now being built as combined district heating/electricity producers. Like R1, both will be located underground.

Switzerland

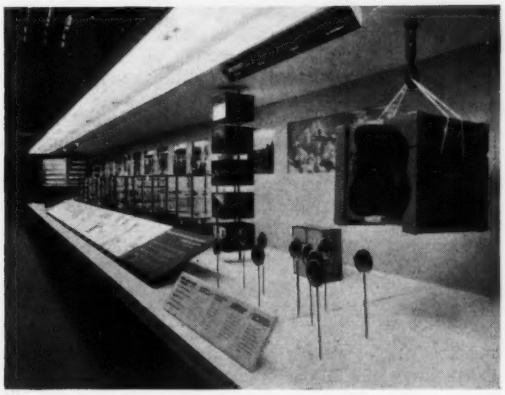
Nuclear research in Switzerland is carried on at Würenlinger, where an atomic energy centre has been established by Reactor Ltd. This concern is financed by more than 170 Swiss companies, although the company receives a Government subsidy. The stand at the exhibition showed by means of photographs some of the facilities of the company. A swimming pool research reactor, SAPHIR, went critical in May, 1957, and another reactor, DIORIT, a heavy-water moderated natural uranium unit for research is scheduled to go critical next autumn. Other facilities include a sub-critical assembly and isotope laboratories.

Japan

It was unfortunate that Japan's exhibit was included in the scientific exhibition because it had a far stronger commercial appeal. Although a general background to the Japanese development of nuclear energy was pictorially presented, the majority of the display was concerned with commercial items of equipment. Hitachi, for example, provided a mass spectrometer and there were metallurgical samples of zirconium and magnesium from Toyo Zirconium and Furukawa Magnesium. Two companies, Showa Denko and Tokai Electrode, featured reactor grade graphite. Part of the stand contained information on the production of heavy water by Asaki Chemical Industry. Showra Optical displayed one of their industrial periscopes suitable for reactor applications. An excellent feature of the Japanese exhibit was the availability of literature covering each item on display. In particular, a booklet entitled "Atomic Energy in Japan " and issued by the Atomic Energy Bureau, Science and Technics Agency, presented an accurate picture of the current stage of development.

(Above) Facade of the main entrance to the commercial Atoms for Peace exhibition at the Palais des Expositions in Geneva.

THE COMMERCIAL EXHIBITION



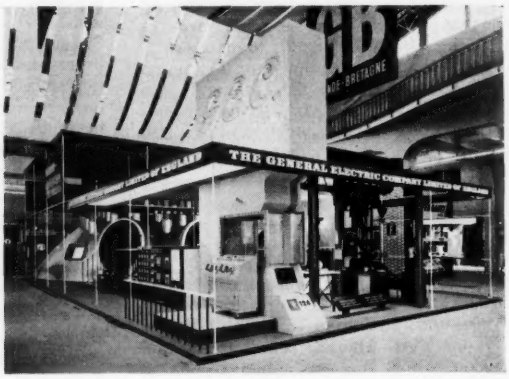
Section of the United Kingdom Atomic Energy Authority's stand at the Commercial Exhibition.

United Kingdom

If the American exhibit in the scientific exhibition was supreme, the honours in the commercial display at the Palais des Expositions must go to Britain. Again, it was not just a matter of sheer size although the British section was by far the largest of the 13 countries represented. Britain triumphed because nearly every exhibitor had equipment for sale—from a complete range of nuclear instruments to power reactors of 500 MW. What is more important, the whole world was showing tremendous interest in this remarkably large and lively productive capacity. Indeed, many U.K. exhibitors have subsequently said that the amount of business placed as a result of the exhibition has considerably exceeded

Panatron units for the radiographic inspection of castings were featured by Nuclear Engineering Ltd.

One of the most impressive stands in the British section was that of G.E.C. Simon-Carves. The full-scale model of the upper part of a Hunterston reactor attracted great interest.



their most optimistic expectations. Because the British section was previewed in the September issue of *Nuclear Engineering*, we shall not discuss it further in these notes. A number of items of new British equipment introduced at Geneva will, however, be described in future issues.

U.S.A.

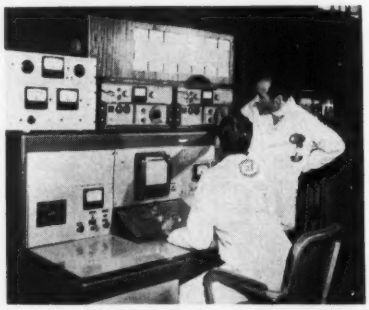
Considering the immense amount of research and development and the broadly based programme of investigation into different types of power reactors, the U.S.A. commercial exhibit was, with a few important exceptions, lacking in interest. The American reputation for salesmanship is world-wide: there was not much evidence of this aggressive quality at Geneva.

Highlights of the American section were two operating research and training reactors by Aerojet-General Nucleonics and Atomics International. The AGN 201 was from the company's series of mass-produced research reactors with a rating of a few milliwatts. The 10-watt L.77 laboratory reactor developed by A.I. was a solution-type contained in a tank 8 ft high by 8 ft diameter. The most appealing exhibit in the U.S. section was undoubtedly an ingenious master slave robot operated by four technicians from Argonne National Laboratory. The equipment comprised a fully mobile slave unit weighing more than a ton and standing some 8½ ft high. The electronically-controlled arms had a reach of 4 ft and stereo-television aided the operator when he was unsighted. Feel was built into the device together with the ability to reject loads which would impose a strain on the slave arms.

A mobile radioisotope laboratory, one of two which were presented to the International Atomic Energy Agency at the end of the conference was also on show. Valued at $56,000 this laboratory was designed for U.S.A.E.C. by Oak Ridge Institute of Nuclear Studies.

The centrepiece of the U.S. commercial exhibition was a full-scale model of the Shippingport core complete with associated control rods. Encircling the model there was an information centre staffed by personnel from the Atomic Industrial Forum and the U.S.A.E.C. This area also contained a general display of the four principal fields of nuclear development: raw materials, fabrication, power production and radiation.

Turning now to U.S. companies offering large power reactors, Westinghouse featured a model of the Yankee Atomic station, Consolidated Edison showed work at Indian Point whilst General Electric displayed a model of Dresden with facilities for simulating operation of the reactor. The Power Reactor Development Company's display concerned the Enrico Fermi fast breeder project. Smaller power reactors were represented on the following stands: Alco Products (50 MW PWR); General Atomics (model of TRIGA and advanced gas cooled project); Atomics International (various power projects ranging from 12.5 to 100 MW).



Operating console of the 10 watt L.77 low power training reactor exhibited by Atomics International.

In addition to the two research reactors in actual operation, other types were being offered by ACF Industries, AMF Atomics, and Curtiss Wright Corporation.

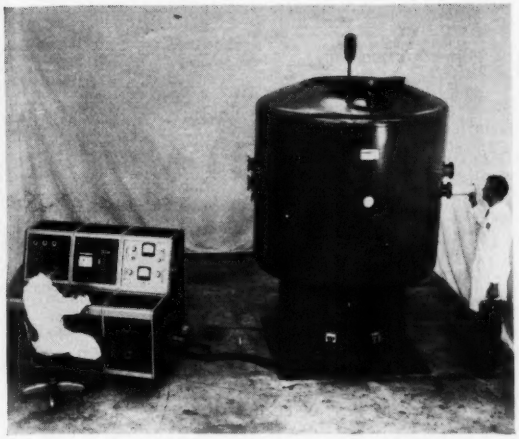
Of the remainder of the 56 U.S. exhibitors, a large proportion offered nuclear materials or fuel elements. Two companies, the Beryllium Corporation and British Beryllium, featured beryllium components; zirconium in shaped form could be seen on the stands of Carborundum Metals, Columbia-National Corporation and Mallory-Sharon Metals Corporation. Fuel elements were featured by the Martin Co., M. and C. Nuclear and Sylvania Corning Nuclear Corporation. Nuclear grade graphite, including a type impervious to hot gases, could be seen on the Union Carbide exhibit. Mallinckrodt Chemical displayed photographs of the world's first commercial facility for the production of enriched uranium.

Although many of the better-known U.S. companies specializing in nuclear instrumentation were present the American effort in this sphere was dwarfed by the exceptionally lively instrument stands arranged by the Scientific Instrument Manufacturers' Association in the British Section.

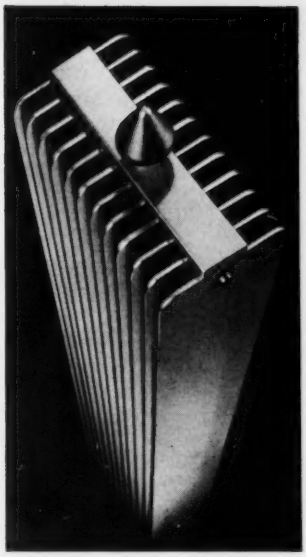
France

Although France was represented by 100 companies, many of them had obviously taken space for prestige or propaganda purposes only. Many items of equipment on show had no part to play in nuclear engineering but were merely examples of the type of work carried out by the exhibiting company. In this respect the French section was reminiscent of the 1955 Atoms for Peace exhibition.

This criticism does not, fortunately, apply to the section of French industry concerned with the supply of raw materials for the nuclear industry. France is, of course, the largest producer of uranium in Europe. Among the largest companies showing nuclear materials and fuel elements were Pechiney (beryllium, zirconium, titanium and nuclear graphite); La Metallurgie Française des Poudres (boron control rods and rare earths); Electro-Chimie Ugine (sodium, zirconium); Ugine-Carbone (boron carbide, heavy tungsten alloys); and Société Industrielle de Combustible Nucléaire (fuel elements for G1, G2 and G3).



This model AGN 201 low power research and training reactor by Aerojet-General Nucleonics was in actual operation on the U.S.A. exhibit.



Fuel element for a training reactor by M and C Nuclear. Twelve fuel plates are held together by a simple spacer and rod with lock washers.

The Commissariat a l'Energie Atomique divided their stand into two parts—one giving visitors a general background of the development of atomic energy, the other describing the Commissariat's achievements so far. The research centres at Saclay, Fontenay-aux-Roses and Grenoble, the production of uranium, the industrial group at Marcoule and the first Electricité de France nuclear power station at Chinon were all described.

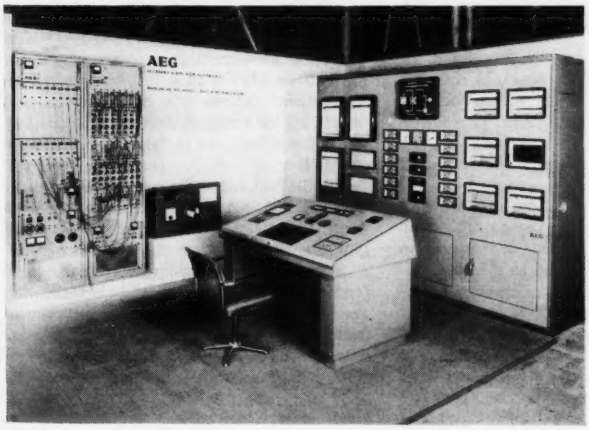
Of the larger French companies represented, France-Atome displayed a model of G2, photographs of member companies' contributions to the high flux EL3 and models of nuclear tankers powered by a boiling water and a pressurized water reactor. Nuclear components and drawings were featured by Indatom. Other exhibitors included: Société Alsacienne de Constructions Mecaniques (general contracting work for reactors G1, G2 and G3 including charge and discharge gear); Société de Forges et Ateliers du Creusot (high-grade steels, heavy-plate fabrication); Société General d'Exploitations Industrielles (industrial architect consultants for various French nuclear projects), and Société Rateau (CO_2 blowers, steam turbines, heavy water pumps).

On the chemical side, the Société Industrielle des Minerais de l'Ouest Etablissements Kuhlmann showed models of factories built to convert uranium ores into uranates, whilst Potasse et Engrais Chimiques S.A. featured a model of a uranothorianite ore processing factory.

A very large number of instrument manufacturers took space in the French section: many of them were also represented on the stand of the Commission de l'Instrumentation Nucléaire Française.

Belgium

Although small in comparison to other countries, Belgium's contribution to the exhibition was nonetheless noteworthy because of the excellent organization of the combined stand representing mining and metallurgical interests on the one hand and electrical and electronic production on the other. From Upper Katanga in the Belgian Congo uranium mined by Union Minière is supplied to Société Generale Metallurgique de Hoboken for refining. Exhibits of this company included uranium oxides and salts and raw and vacuum-smelted nuclear pure uranium for use as fuel elements. Also represented on the stand was Belgo-nucleaire, a consortium of nearly 50 Belgian companies, which acts as a consulting engineer in nuclear matters. Belgo-nucleaire has already contributed towards the design of an 11.5-MW experimental reactor, BR3, which is being constructed at Mol. In conjunction with the General Nuclear Engineering Corporation, the company has also put forward a proposal for a 124-MW(E) boiling water power reactor. Another company interested in building a power reactor is A.C.E.C., who hold a licence from Westinghouse and have a working agreement with the Cockerill-Ougree group. A 220-MW(E) pressurized water reactor has been proposed by A.C.E.C. At the present time a group of Belgian consultants is examining the possibility of constructing a power reactor of about 125 MW at Mol. Apart from the companies mentioned above, British and American companies are understood to have submitted proposals for this station.



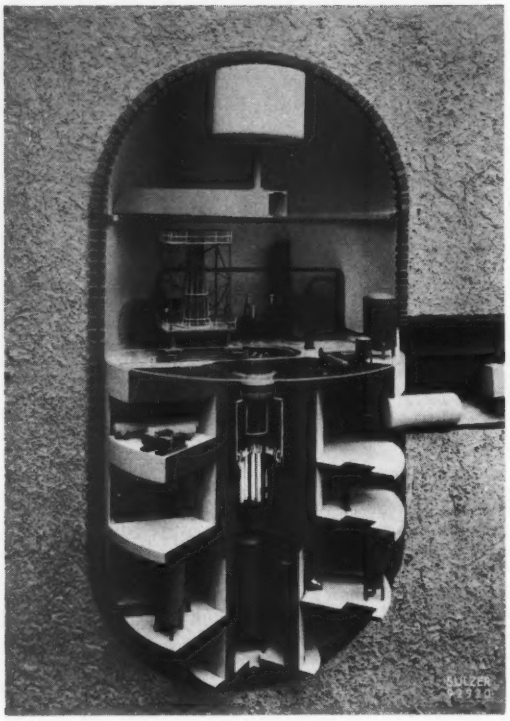
This power reactor simulator was featured by A.E.G. in the German section.

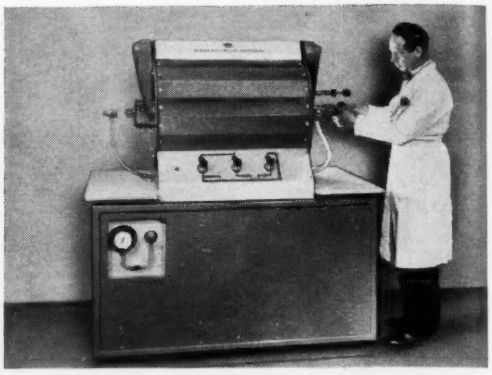
Switzerland

If Swiss representation at the exhibition is anything to go by, manufacturers there are particularly anxious to participate in nuclear contracts. Sulzer Bros., for example, provided a model of a 30 MW nuclear power plant which is to be combined with district heating for the Swiss Federal Institute of Technology at Zurich. A large colour transparency indicated the principal circuits of the station with a cross section of the natural uranium heavy water moderated reactor. The station will have an Escher Wyss steam turbine. Oerlikon Engineering will also contribute to this project. Sursatom A.G. featured a model of the 25 MW AARE pilot power reactor to General Electric design which is to be built in conjunction with Brown Boveri.

Brown Boveri's stand included a full-scale model of a heavy water reactor with provision for visitors to operate the control rods. Other exhibits included a heavy water pump and a sample weld in thick steel plate.

Yet another reactor model could be seen on the exhibit of Energie Nucleaire (ENUSA), a group of public companies which proposes to erect an experimental power reactor at an underground station in the French part of Switzerland. The





(Above) Siegbahn - Slätis beta-ray spectrometer by LKB of Sweden.

Model of the 30 MW nuclear power plant and district heating station which Sulzer Bros. are to build for the Swiss Federal Institute of Technology.

boiling water reactor will use slightly enriched uranium oxide as fuel and light water as moderator and coolant. The plant has been designed by another Swiss group known as CIEN.

Swiss companies showing equipment of interest included Ateliers des Charmilles (fuel element guides); Vevey Engineering Works (stainless steel fabrications); Oerlikon Engineering (reactor blowers); S. A. des Ateliers de Secheron (canned induction motor for heavy water pump); Chaudronnerie d'Aluminium (reactor tanks and vessels in aluminium); Fabrique d'Appareillage Electrique Sprecher et Schuh S.A. (reactor control room); Emile Haefely (pulse current capacitors for fusion experiments); Landis and Gyr (nucleonic instruments); Usines Jean Gallay S.A. (stainless steel tubes and drums for transporting radioactive waste) and Weka, AG (stainless steel fabrications).

Germany

The German section was typical of the country's rapidly expanding production capacity for nuclear engineering. Although late starters German manufacturers are obviously determined to win a share of any new business in the nuclear field. No fewer than three German companies were offering power reactors at the exhibition. Interatom, a company jointly owned by Demag of Duisburg and Atomics International, featured two models of a 100 MW(E) organic moderated reactor. This type of reactor has also been put forward by Atomics International for marine propulsion applications.

A.E.G. featured a model of a twin reactor nuclear power station, with a total rating of 200 MW. Moderated and cooled by light water, each reactor is housed in a pressure-tight steel shell together with its associated heat exchangers. A sectional model showed six heat exchangers arranged in star form around the reactor. A power station reactor simulator comprising an analogue computer, instrument panel, control desk and a rod drive mechanism was also featured on A.E.G.'s stand.

A most interesting exhibit in the German section was the model of a 130 MW natural uranium heavy water reactor which has been developed by Siemens-Schuckertwerke. The model comprised a $\frac{1}{3}$-scale cross-sectional view of the reactor with provision for illuminating the fuel elements to simulate a rise in reactivity. The control and scram rods could be actuated from a nearby control desk by visitors. The reactor is of the pressure vessel type fuelled with natural uranium in the form of zirconium-clad sintered uranium dioxide. The heavy water coolant and moderator is pressurized to prevent steam generation in the reactor. Internal diameter of the pressure vessel is 4.3 m (14.1 ft) and the height between dome-shaped ends is 9.5 m (31 ft), with an operating pressure of 120 kg/cm^2 (1,700 p.s.i.g.), the wall thickness of the cylindrical centre section will be 150 to 200 mm (6 to 8 in.). Provision is made for fuel elements to be replaced while the reactor is operating.

Degussa has a considerable experience in the manufacture of rare metals and it was therefore not surprising to see a wide range of nuclear materials, on the company's stand. Exhibits included uranium, thorium, zirconium and calcium. So far as fuel elements are concerned Degussa has facilities for making them from uranium metal, uranium monocarbide, uranium oxide and sintered uranium oxide. Thorium breeder elements are also available from Degussa.

Degussa also featured a model of their heavy water plant with a production capacity of 10 tons/year. The process is based on the isotope exchange between hydrogen and water in liquid phase in the presence of a suspended catalyst. Plant for heavy water production was also displayed in model form on the stand of Pintsch Bamag, the process involving the H_2S dual temperature exchange method. This company had two other models—an Argonaut research reactor and a waste water decontamination plant for IKB, Berlin.

Heavy plate fabrication and allied equipment was illustrated on the stand of Rheinische Stahlwerke Ruhrstahl. Amongst the many German instrument manufacturers were Willi Reichert (survey meters, gamma monitors and pulse counters); Siemens and Halske (reactor simulator, neutron flux measuring channels) and Frieseke and Hoepfner (monitors and detectors). Nuclear graphite was featured by Siemens-Plania; heat exchanger tubes by Peco; radiation shielding glass by Jenaer Glaswerk and manipulators by Leybold.

Netherlands

Philips have made many contributions to nuclear engineering and a selection of their products was displayed. Models included an accelerator in a pressurized tank, a 28 MeV and a 150 MeV synchrocyclotron. There was also a swimming pool reactor control desk.

Sweden

LKB-Producter Fabriksaktiebolag of Stockholm displayed a Siegbahn-Slätis beta spectrometer which is widely used for the measurement of particle energies.

The Scintigraph equipment by the same company allows whole-body scintillation scanning to be carried out fully automatically, the scintigram being recorded in scale 1 : 4. Detailed studies of parts of the patient's body (max. 560 mm by 420 mm) are possible with recording in full scale.

Orbits in Industry

LOOKING back on Geneva, one can hardly say that . . . "the mammoth three-ring circus has struck its tents . . ." etc. In the first place, there would be no striking of tents—the marble barracks that housed the show, and in which one got lost with monotonous regularity, had a very solid and permanent air about it. Secondly, "three-ring" is an under-statement. There were, at times, no fewer than five technical sessions running simultaneously, which made it great fun for those with a diversity of interests; it not only led to incipient schizophrenia, but it kept their weight down, ankling round what the Palais plan describes as the "galerie des pas-perdus." If they had made it "pieds-perdus," it would have been nearer the mark.

Too Big

Other, and more serious pens have pointed out that the Conference is too big, but this, of course, will not deter the Tangential two-pennorth. It would seem far better to have two or three less all-embracing conferences. Even if it only split into two halves, and separated the biologists from the heavy plumbers, it would at least be something.

A distinguished Belgian biologist who happened upon Tangent, engaged in restoring his jaded tissues with a glass of milk, pointed out that considerable overlapping was inevitable and instanced protection as the dual province of the engineer and the biologist. But is it? Surely the biologist is interested in fixing levels of tolerance while the engineer is interested in the design of shielding to meet the requirements laid down by the biologist, and not in the actual cell-mutation?

If there ever should be another single conference on the same scale, at least let us try to sectionalize the Press conferences. The method adopted, of dealing at the end of each session with the entire bag, one after the other, may be admirable in theory, but that is all. What it boils down to is that the earnest type wishing to ask one (1) simple question on a power reactor paper, sits with paralyzed posterior through two hours of bright chit-chat about the mining of uranium ores, the production of trans-uranium elements* in weighable amounts; the instrumentation of the fusion process, and the breeding habits of irradiated flies; a whole hour was devoted to this last subject, because it appeared to be a particular interest of the bloke conducting the proceedings. Finally, of course, a combination of physical paralysis, mental numbness, thirst, and what we have always understood the Foreign Legion calls *cafard* or desert-madness, leads to a desperate struggle to get out, and the question never does get asked, let alone answered. (Probably it serves us right for being a narrow-minded crotchety old meanie. . . . No Breadth of Vision. . . . Pity!)

* Apparently one-quarter of a microgram of Berkelium was produced from 100 g of plute. after five years intensive bombardment. The prospects of marketing on a tonnage basis are not stated.

Press Gang

As one rather gloomily expected the arrangements for obtaining papers were of the on-depressing-the-kick-starter-the-engine-should-fire variety but, once again, desire outran performance. A simple system (entailing only filling-in a form, chasing round for signatures from someone who never seemed to be there, and handing over the form for subsequent loss in the bowels of the Palais) broke down the first day and was replaced by another system. This didn't work either, but in a different way, so it made a change. The only real thing to do was to wait until a pile of papers of some sort or other was laid on a table and then fight one's fellow pressmen for it. . . . Nature red in tooth and claw . . . etc., and hope that when one did emerge from the fray, battered and bent, that one had not merely spent one's blood in acquiring two copies of yesterday's programme in French.

There was one bright spot in this realm of Good King Utter Choss, and his name was Riley. He did his best, but the system beat him. However, he was cheerful, he was polite, he did not shrink from facing the frenzied mob, nor yield to the temptation of pretending that he did not understand English. His demeanour throughout was that of an air hostess facing a crash; soothing those he could not save. Men have been decorated for less.

Gentlemen v. Players?

Both the exhibitions were well worth seeing, but one (at least, this one) wonders why it was necessary to have two, so far apart. The impression one gets is rather that those responsible shrank from the contaminating influence of sordid commercialism, with the result that there was a lot of divided effort. In the scientific exhibition, there can be little doubt that the U.S. scored; the full-size model of the Shippingport reactor was one of the most impressive exhibits seen. In the commercial exhibition, however, the British display was so far ahead of all others as to cause the spreading of uncharitable rumours concerning Government subsidy, and one had some difficulty in persuading people that it was not true. The general argument seemed to be that no commercial organization could afford publicity on that scale, to which the only answer is, of course, that Britain is *really* in the nuclear energy business. That, to Tangent, seemed the keynote not only of the exhibition but of the entire conference. There have been hard things said elsewhere of our meagre achievements in physics, apparently because we do not yet own an accelerator as big as the Inner Circle. On the practical side, however, we are in business on a practical scale; not going through the motions for the sake of national prestige. If only we had a Union Jack (as it is always miscalled), we would end this burst of patriotic fervour by waving it.

Optical Illusion

For our money, the most interesting exhibit in the commercial exhibition was that of the G.E.C. The idea of having a full-size model of the top of a pressure vessel may have been a gimmick, but it was a good one, and really gave the average man some idea of the size of a reactor. Walking in through one of the gas ducts, it took one some time to realize that only one-quarter of the area was really there, with a couple of very large mirrors at right angles yet, until one noticed a certain familiarity in the appearance of the other three shabbily dressed chaps lounging around inside, the illusion was perfect. So perfect, in fact, that the G.E.C. had to put white ropes up to stop people walking through the glass and, even then, they asked if they could go round outside.

DR. FINAGLE'S LAWS—4

Law of the Lost Inch

In designing any type of construction, no overall dimension can be totalled correctly after 4.40 p.m. on Friday.

Corollary I: Under the same conditions, if any minor dimensions are given to sixteenths of an inch, they cannot be totalled at all.

Corollary II: The correct total will become self-evident at 9.01 a.m. on Monday.

"Advanced Type"

Overheard at Geneva:

". . . Interesting reactor. What type? . . . Oh, just like most of the others described here . . . paper-moderated, ink-cooled."

By Any Other Name?

In deference to the general change in public outlook on atomic missiles, a Derbyshire nurseryman has just re-christened one of his bright red roses "Velvet Robe." Its previous title was "Atom Bomb." Presumably this is a case of soft-petalling.

Tangent

National Power Programmes (pages 419-421)

Programmes et Aspects Economiques de Puissance Nationaux

Une étude des mémoires soumis à la Conférence a révélé que, comme on devait s'y attendre, les plans des constructions d'énergie nucléaire—sauf une ou deux exceptions—ont reflété les ressources traditionnelles de combustible de chaque pays ainsi que leur besoin d'énergie électrique.

Le Canada envisage une capacité montée de 200–1,000 MW pour 1966, s'élevant à 4,000–7,000 MW en 1981. On croit maintenant qu'une centrale de 200 MW peut être construite pour faire concurrence au charbon à $9 la tonne, par l'emploi d'eau lourde et l'omission du cyclage du combustible.

En France, bien que les importations de combustible s'élèvent à 40% du total, la philosophie tend vers l'expérience plutôt que vers un programme déterminé. La première grande centrale (EDF 2–120 MW) est prévue pour 1962; des centrales plus petites de 30 MW sont, bien entendu, en fonctionnement et un groupe de 62 MW (EDF 1) est prévu pour 1960.

Le programme de la Russie comprend une centrale de 420 MW dans le Borovezh et une centrale expérimentale de 400 MW est en construction à Beloyarsk. Une centrale de 600 MW sera commencée sous peu. Le réacteur rapide de 5 MW devra entrer en fonctionnement sous peu, ce qui est le cas du brise-glaces " Lénine " de 44,000 CV.

Aux Etats-Unis, Shippingport, EBWR et ORME fonctionnent tous avec succès. En dépit de réserves de combustible considérables, on s'attend à ce que la production d'énergie nucléaire, en mesure de faire concurrence, devienne disponible dans une dizaine d'années.

L'Inde s'attend à avoir 1,000 MW en 1966 et 12,000 MW pour 1984.

Cuba installera un groupe de 22 MW de construction britannique pour 1961.

L'Allemagne s'attend à avoir 500 MW pour 1965.

L'Italie a passé deux contrats, l'un pour une centrale de 150 MW avec la Grande-Bretagne.

Le Japon considère déjà l'énergie nucléaire comparable aux combustibles traditionnels et s'attend à avoir 600 MW en 1965 et 7,000 MW pour 1975.

Les Pays-Bas envisagent avoir des installations nucléaires équivalant à 35% de la capacité totale pour 1975; le programme de la Pologne prévoit 800 MW pour 1970 et 1,800 MW pour 1975.

L'intérêt de la Suède se porte vers des réacteurs à usages multiples et six groupes de 75–100 MW sont au programme pour jusqu'à 1965, en plus d'un nombre d'autres groupes de grandeur comparable. Une capacité installée de 2,000 MW est prévue pour la période 1965–1975.

Ni l'Espagne ni la Roumanie n'auront d'installations nucléaires à un degré appréciable avant 1965–1970.

Le programme britannique a été passé en revue si souvent dans ces pages qu'il est à peine nécessaire de le répter ici. En plus de Calder Hall et de Chapel Cross, quatre grandes centrales commerciales, d'un total d'environ 1,600 MW sont en construction, et on s'attend à ce que la première entre en service en 1960.

Krafterzeugungs- und Wirtschafts-Programm der Nationen

Eine Uebersicht über die Vorträge auf der Konferenz zeigt, wie erwartet, dass die Pläne zum Aufbau von Atomkraftwerken—mit ein oder zwei Ausnahmen—ein Spiegelbild der Brennstofflager jeder Nation sowohl, als auch ihres Bedarfes an Elektrizität darstellen.

Kanada beabsichtigt bis 1966 Einrichtungen für eine Stromlieferung von 200–1,000 MW zu haben, die bis 1981 auf 4,000-7,000 MW anwachsen sollen. Gegenwärtig glaubt man, dass ein 200 MW Werk gebaut werden kann, das mit einem Kohlenkraftwerk bei einem Preis von $ 9 die Tonne in Wettbewerb treten kann, wenn schweres Wasser benutzt und Brennstoffumlauf weggelassen wird.

In Frankreich, wo importierte Brennstoffe 40% des gesamten Verbrauchs ausmachen, ist man trotzdem mehr darauf bedacht, auf Erfahrungen weiter zu bauen anstatt nach einem festen Programm zu arbeiten. Das erste grosse Werk (EDF 2–120 MW) soll 1962 fertig sein; kleinere Werke von 30 MW sind natürlich schon in Betrieb, und ein 62 MW Werk (EDF 1) soll 1960 fertig sein.

Das russische Programm umfasst ein 420 MW Werk im Borovezh und eine Versuchsanlage von 400 MW, die in Beloyarsk im Bau ist. Ein 600 MW Werk soll demnächst begonnen werden. Der 5 MW schnelle Reaktor soll bald in Auftrag gegeben werden, ebenso der Eisbrecher " Lenin " von 44,000 PS.

In den Vereinigten Staaten arbeiten Shippingport, EBWR und OMRE erfolgreich. Trotz der ungeheuren Brennstoffreserven erwartet man, dass die Krafterzeugung in Atomkraftwerken innerhalb der nächsten 10 Jahre wettbewerbsfähig sein wird.

Indien erwartet 1,000 MW bis 1966 bereit zu haben und 12,000 MW bis 1984.

Kuba ist dabei ein in England hergestelltes 22 MW Werk bis 1961 zu errichten.

Deutschland erwartet 1965 500 MW zu haben.

Italien hat zwei Kontrakte abgeschlossen, einen mit England für ein 150 MW Werk.

Japan hat bereits Atomkraftpläne, die mit gebräuchlichen Brennstoffen den Vergleich aushalten können, und hofft 600 MW bis spätestens 1965 zu haben und 7,000 MW bis 1975.

Die Niederlande erwarten Atomkraft zur Erzeugung von 35% der gesamten Leistung bis spätestens 1975 bereit zu haben.

Polens Programm sieht 800 MW bis 1970 und 1,800 MW bis 1975 vor.

Schweden hat Interesse für vielseitig nutzbare Reaktoren; sechs 75–100 MW Werke sind geplant, die 1965 fertig sein sollen in Ergänzung einer Anzahl anderer Werke von vergleichbarer Grösse. Die Fertigstellung von Werken mit einer Leistung von 2,000 MW ist für die Periode 1965–1975 vorausgesagt worden.

Weder Spanien noch Rumänien werden irgendein Atomkraftwerk von in Frage kommender Leistung vor 1956–1970 haben.

Ueber das englische Programm ist so häufig auf diesen Seiten hier berichtet worden, dass es kaum notwendig ist alles hier zu wiederholen. In Ergänzung von Calder Hall und Chapel Cross sind vier grosse kommerzielle Werke im Bau mit einer Gesamtleistung von fast 1,600 MW, und man hofft, dass das erste Werk im Jahre 1960 den Dienst aufnehmen wird.

Programas Nacionales de Energia y su Economia

Un vistazo a los documentos de la Conferencia demuestra que, como debieramos esperar, los planes de construcción de energía nuclear—con una o dos excepciones, reflejan los orígenes convencionales de cada uno de los países así como su apremiante necesidad de energía eléctrica.

Canadá contempla una capacidad instalada de 200–1000 MW para 1966, que habrá de elevarse a 4000–7000 MW para 1981. En la actualidad se espera que podrá construirse una planta de 200 MW para competir con el carbón a $9.– por tonelada, valiéndose de agua pesada y omitiendo los ciclos de combustible.

En Francia, aunque las importaciones de combustible se elevan al 40 por ciento del total, lo que se quiere es más bien experimentar que fijar un programa determinado. La primera planta grande (EDF 2–120 MW) debe estar lista para 1962; otras plantas más pequeñas de 30 MW están ya, naturalmente, en funciones y otra unidad de 62 MW (EDF 1) deberá comenzar en 1960.

En el programa de Rusia se incluye una estación de 420 MW que está en construcción en Beloyarsk. Otra planta de 600 MW deberá comenzar a construirse en breve. El reactor rápido de 5 MW deberá entrar en operación pronto, como ocurre con el famoso rompe-hielos " Lenin " de 44,000 H.P.

En los Estados Unidos de Norteamérica, las plantas de Shippingport, EBWR y OMRE vienen funcionando perfectamente. Pese a las enormes existencias de combustible se cree que la generación competitiva de energía nuclear se dejará sentir dentro de 10 años.

India confía contar con una planta de 1000 MW en 1966 y 12,000 MW en 1984.

Cuba va a instalar una unidad enteramente británica de 22 MW para 1961.

Alemania a su vez, espera contar con 500 MW en 1965.

Italia ha concertado ya dos contratos, uno para una estación de 150 MW en Gran Bretaña.

Japón viene también estudiando estaciones de energía nuclear comparables a las de combustibles convencionales y espera tener 600 MW para 1965 y 7000 MW para 1975.

Los Países Bajos esperan contar con plantas nucleares equivalentes al 35 por ciento de su capacidad total para 1975; en el programa de Polonia se incluyen 800 MW para 1970 y 1800 MW para 1975.

Suecia está interesada en reactores de fines múltiples y se planean seis unidades de 75–100 MW para 1965 además de cierto número de unidades de tamaño comparable. La capacidad instalada para el período de 1965–1975 es de 2000 MW.

Ni España ni Rumania contarán con equipo alguno nuclear de consideración antes de 1965–1970.

El programa británico ha sido revisado tantas veces en estas páginas que casi no es necesario repetirlo ahora. Además de Calder Hall y Chapel Cross, otras cuatro grandes estaciones comerciales con un total de casi 1600 MW están ya en construcción, la primera de las cuales deberá entrar en servicio en 1960.

Nuclear Fuel Resources (page 422)

Fourniture de Combustibles Nucléaires

Sur le continent nord-américain, des minerais qui peuvent être travaillés de façon à donner des concentrés valant $10 *la livre sont considérés comme exploitable. Ceci veut dire que des concentrés n'excédant pas* 0,1% *aux Etats Unis ou* 0,075% *au Canada sont utilisés.*

On évalue les réserves connues dans les pays non-communistes à 1.500.000 *de tonnes d'oxide d'uranium et vraisemblablement* 2.000.000 *de tonnes supplémentaires pourraient être développées dans un temps limité. Le taux de production annuel des pays non-communistes est d'environ* 35.000 *tonnes et devra atteindre* 42.000 *tonnes en* 1959.

Lager von Atom-Brennstoffen

Erze auf dem nord-amerikanischen Kontinent, die nach der Aufbereitung des Konzentrats für $10 *je Pfund (engl.) verkäuflich wären, werden als verwertbar angesehen. Dies schliesst so niedrige Konzentrate ein wie* 0,1% *in den Vereinigten Staaten und* 0,075% *in Kanada.*

Entdeckte und erforschte Lager in den nicht-kommunistischen Ländern werden auf 1.500.000 *t Uranoxyd geschätzt, und man glaubt, dass noch zusätzliche* 2.000.000 *t innerhalb einer angemessenen Periode erschlossen werden können. Die gesamte Jahresproduktion in nicht-kommunistischen Ländern ist ungefähr* 35.000 *t und sollte auf* 42.000 *im Jahre* 1959 *gestiegen sein.*

Suministros de Combustible Nuclear

En el continente Norteamericano existen minerales que pueden ser tratados para dar un concentrado que pudiera venderse a razón de $10.- *por libra, y estos minerales se consideran asequibles. Esto significa concentraciones tan bajas como el* 0.1% *para Estados Unidos y* 0.075% *en Canadá.*

Las reservas exploradas ya en paises no comunistas se calculan en 1,500.000 *toneladas de óxido de uranio y se cree que otras* 2,000.000 *de toneladas podrá ser trabajadas dentro de un periodo razonable. La producción total anual en los paises no comunistas es de aproximadamente* 35.000 *toneladas y debiera alcanzar las* 42.000 *toneladas en* 1959.

Thermo-nuclear Research (pages 423-427)

Recherches dans le domaine Therm-Nucleaire

Bien que la production de réactions thermo-nucléaires soit le but recherché par les études actuelles de la fission, l'objectif final étant une machine productrice d'énergie, on reconnaît qu'il y a beaucoup à apprendre au sujet du comportement du plasma et un grand nombre des machines actuellement en construction sont en prédominance du caractère de dispositifs de recherches.

La retenue du plasma est invariablement au moyen de champ magnétiques, mais la forme de ces champs varie considérablement, comme c'est le cas aussi de la méthode de chauffage du plasma. De brefs détails sont donnés dans l'article au sujet des plus importants parmi les dispositifs expérimentaux, ainsi qu'au sujet de la méthode particulière de retenue et de chauffage adoptée.

Les dispositifs les plus passionnants discutés à Genève ont été les machines à injection et à retenue à miroir des Etats-Unis et de la Russie (DCX et OGRA). Il s'impose de faire ressortir que même ces machines ne donnent lieu à aucune prévision de gain d'énergie pour de nombreuses années.

Thermo-nukleare Forschung

Wenn auch die Herbeiführung von thermo-nuklearen Reaktionen zur Zeit das Ziel der Forschung ist, die Spaltungsvorgänge behandelt, mit dem Endziel der Herstellung einer Kraft erzeugenden Maschine, so ist man sich doch bewusst, dass man noch sehr viel über das Verhalten des Plasmas zu lernen hat, und viele der zur Zeit im Bau befindlichen Maschinen sind in der Hauptsache charakteristische Forschungsapparaturen.

Das Plasma ist ohne Unterschied durch Magnetfelder zusammengehalten, jedoch ist die Form dieser Felder sehr mannigfaltig, und dies trifft ebenso auf die Art der Erhitzung des Plasmas zu. Es werden Einzelheiten über die hauptsächlichsten experimentellen Apparaturen kurz gebracht, einschliesslich Angaben über die besondere Methode des Zusammenhaltens des Plasmas und der Erhitzung.

Die sensationellsten Apparaturen, die in Genf diskutiert wurden, waren die Maschinen, die mit Injektion und Zusammenhalten durch Spiegel arbeiten, welche von den U.S.A. und von Russland gebracht wurden (DCX und OGRA). Es muss aber betont werden, dass man auch von diesen auf viele Jahre hinaus keine wirkliche Energie-Ausbeute erwartet.

Investigación Termo-Nuclear

Aunque la producción de reacciones termo-nucleares es hoy la meta principal de la investigación sobre fisionabilidad, con la máquina productora de energía como objetivo final, se reconoce que ya se ha adelantado mucho en el conocimiento sobre el funcionamiento del plasma y muchas de las máquinas que actualmente se vienen construyendo, son en realidad de carácter predominantemente investigador.

La dominación del plasma se hace invariablemente por campos magnéticos, pero la calidad de estos campos varia mucho como varía igualmente el método de calentar el plasma. Se ofrecen breves datos sobre los más importantes dispositivos experimentales y del sistema especial de dominación y calentamiento adoptados.

Los más excitantes dispositivos discutidos en Ginebra fueron las máquinas de inyección y dominación por espejo de U.S.A. y de Rusia (DCX y OGRA). Debemos recalcar que, ni aún estos, se espera que produzcan una ganacia en energía por muchos años.

Water Reactor Survey (pages 435-437)

Reacteurs à Eau

Dans un compte-rendu des dossiers sur les réacteurs à eau, il est indiqué que le réacteur à eau pressurisé est maintenant établi aux Etats-Unis et en Russie. Son principal désavantage est la basse température ainsique que la basse pression de vapeur, causant une perte dans son efficacité et dans la grande installation d'une machine à vapeur, ou le besoin d'un surchauffage séparé. Shippingport doit être considéré comme une expérience de grande dimension et ne doit pas être utilisé pour tirer des conclusions sur le côté économique du réacteur à eau pressurisé.

Un intérêt grandissant dans le réacteur à eau bouillante a été remarqué comme étant le principal changement depuis la conférence de 1955 *et on le considére comme ayant de plus grandes possibilités, bien que l'expérience seule en a prouvé l'économie et la sûreté. La question qui demande encore une investigation est la possibilité prolongée de contamination de vapeur radio-active avec un dispositif à cycle ouvert. L'économie des réacteurs à eau légère pivote sur le coût incertain d'un combustible enrichi.*

Wasser-Reaktoren

In einer Uebersicht über Wasser-Reaktoren wird gezeigt, dass der PWR (Druckwasser-Reaktor) in den U.S.A. sowohl als auch in Russland jetzt als normal angesehen werden kann. Sein grösster Nachteil ist die niedrige Dampf-Temperatur und der niedrige Druck, was geringere Wirtschaftlichkeit und eine grosse Verdampfungs-Anlage oder die Notwendigkeit getrennter Ueberhitzung bedeutet. Shippingport muss als ein Experiment in grossem Masstabe angesehen werden, und man sollte es nicht benutzen, um daraus irgendwelche Schlüsse auf die Wirtschaftlichkeit des PWR zu ziehen.

Der grösste Unterschied gegenüber der Konferenz von 1955 *ist das verstärkte Interesse für den BWR (Siedewasser-Reaktor); man ist der Meinung, dass er grössere Möglichkeiten bietet, obwohl nur Erfahrung zeigen kann, wie wirtschaftlich und sicher er sein kann. Ein Punkt, der noch untersucht werden muss, ist die Möglichkeit langdauernder Vergiftung durch radioaktiven Dampf im offenen Umlauf. Die Wirtschaftlichkeit des Frischwasser-Reaktors hängt von den ganz ungewissen Kosten angereicherten Brennstoffes ab.*

Reactores al Agua

En una revista de documentos sobre reactores al agua, se señala que el PWR (reactor al agua a presión) se ha establecido ya tanto en U.S.A. como en Rusia. Su principal desventaja es la baja temperatura y presión del vapor, lo que acarrea una pérdida en efectividad y la necesidad de disponer de un equipo grande para vapor o la necesidad de un recalentador individual. Shippingport debe ser considerado solamente como un experimento a gran escala y por eso no podemos valernos de él para llegar a conclusiones sobre la cuestión económica del PWR.

El cambio principal desde que se celebró la Conferencia de 1955, *es el mayor interés en el BWR (reactor de agua hirviente) y se considera, ue ofrecen mayores posibilidades, aunque solamente la experiencia podrá hasta qué punto resultan económicos y seguros. El punto que todavía exige bastante investigación es la posibilidad a largo plazo de la contaminación radio-activa del vapor con un dispositivo de ciclo abierto. La cuestión económica de los reactores de agua ligera estriban en el costo incierto del combustible enriquecido.*

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 792,170. Fuel element for nuclear reactors. To: Physikalische Studiengesellschaft Düsseldorf G.m.b.H. (Germany).

The formation of plutonium on a large scale is not always desirable in power reactors as the neutron yield in the fission of plutonium is relatively unfavourable, especially with slower neutrons. Additional neutron losses occur through resonance absorption on the surface of the uranium body, as the capture cross-section of uranium is larger for medium-fast neutrons than for thermal neutrons, so that the medium-fast neutrons are captured only in the neighbourhood of the surface of the uranium body. It has now been found that coating the uranium body with thorium, although it has a very large capture cross-section for medium-fast neutrons, has the great advantage that the Th232 changes into Th233 due to neutron capture and then forms U233 by decomposition with beta-radiation. U233 is far superior as a fissionable element to plutonium and gives an appreciably higher neutron yield, even with slow neutrons. Neutrons of medium energy are thus utilized for the formation of U233, instead of forming the undesirable plutonium. Thorium may be applied in the form of a mouldable compound (as an oxide, carbide, nitride, silicide) around a core of a homogeneous mixture of uranium with a graphite or beryllium compound as a moderator.

B.P. 792,171. Heat removal systems for nuclear reactors. J. le Foll, G. Melese. To: Commissariat à l'Energie Atomique (France).

Heat generated in the fuel rod channels is removed by a circulating coolant so that the temperature of the materials in the core remains within a certain range. The neutron flux, however, is a maximum in the central portion of the reactor, and this determines the temperature limit of the fissionable material. In the peripheral portion of the reactor, the allowable maximum temperature of the casing is the limiting factor. Highest possible thermodynamic efficiency would require that every channel worked at its permissible temperature, but this cannot be achieved if the coolant is fed at the same pressure and temperature to all channels, and the outlet temperature is restricted to the allowable maximum of the central section. The channels are, therefore, divided into a number of groups, such that the neutron flux of all channels of each group falls within a given range. Coolant is separately fed to each group, at a temperature and pressure adapted to its temperature limit, so that within each group the best possible average thermodynamic efficiency is obtained.

B.P. 792,347. Refinement of fissile metals. J. E. Antill. To: U.K. Atomic Energy Authority.

Refers to the removal of all fission products from metallic fuel elements after irradiation in a nuclear reactor without converting the metal from the metallic stage. A charge of at least one non-metallic compound (uranium oxide, sulphide or carbide) which is immiscible with the metal (uranium) and has an affinity for fission products, is added in the bottom of a (beryllium oxide) crucible under an ingot of irradiated metal and the charge and the ingot are then subjected to a zone melting process, e.g., by passing the assembly vertically downwards through an electric furnace at the rate of 0.25 in./hour, when most of the activity arising from fission products will concentrate in the top 2cm of the ingot.

B.P. 792,401. Closure for pressure vessel. To: Babcock and Wilcox Co. (U.S.A.).

Closures secured by studs and nuts are held tight against a seating by heating the studs to a predetermined temperature, and screwing down the nuts. The tension is then increased upon cooling, the nuts can be rotated, and the closure applied, from a remote position.

B.P. 792,424. Radiation indicator, particularly for radioactive radiation. To: Forsvarets Forskningsinstitutt. (Norway).

A thin leaf carried by an extended conducting filament constitutes the movable electrode of an electrometer. When moving towards the fixed electrode the leaf rotates about the axis of the filament. The leaf is so arranged that each time a certain charge has been attained, it will make contact with the fixed electrode and then immediately swing back to start again. The oscillation frequency of the leaf will give an indication of the intensity of the occurring ion current and hence of the radiation received (gamma radiation after an atomic explosion).

B.P. 792,447. Cobalt-chromium alloy. G. T. Harris, H. C. Child. To: William Jessop and Sons Ltd.

Alloys of a minimum cobalt content of 41% and cerium up to 1% (as ferrocerium; mischmetal; mixed rare earth oxides with a suitable deoxident; any cerium rich alloy). The properties include rupture strength at high temperatures and forgeability. (Adds to B.P. 674,023.)

B.P. 793,297. Method of and apparatus for detecting breaks in nuclear reactor fuel rod sheaths. To: Atomic Energy of Canada, Ltd. (U.S.A.).

The method previously used in light or heavy water-cooled reactors consisted in conducting the cooling water from the fuel rods past a gamma ray detector and measuring the gamma activity of the water. In the case of a sheathing failure there will be an increase in the specific activity. This method, however, is not very sensitive, is unreliable and may lead to contamination. In the new method, a neutron detector is placed near the duct carrying the effluent coolant from the reactor at such a distance from the reactor (fuel element) that neutron-emitting radioactive substances in the coolant having half-lives not exceeding that of N^{16}, and gamma-ray-emitting radioactive substances capable of producing photo-neutrons and having half-lives not exceeding that of N^{17} decay to a negligible activity value. Neutrons released in the coolant by the decaying of fission products, which have entered the coolant through a perforation failure in the sheath, are detected in a neutron counter assembly to which an amplifier and discriminator is attached. When working with heavy water the masking effect of photo-neutron activity is minimized by purification of the heavy water, by allowing only a small volume of it near the counter, and by delaying the heavy water in the path from the reactor to the counter.

B.P. 792,951. Production of uranium and plutonium. R. H. Myers. To: U.K. Atomic Energy Authority.

Metal of high purity, suitable for conversion into shapes without the need for casting, is obtained by a process in which a mixture of a powdered oxide of the metal and particulate alkaline earth metal is heated to produce a reaction product of beads of the uranium or plutonium metal, dispersed in a mass of alkaline earth metal oxide. This is leached with water and/or aqueous acid (aqueous nitric acid of 20% concentration). The metal can be compacted and sintered, in vacuo or in a protective atmosphere.

B.P. 792,952. Production of uranium. R. H. Myers. To: U.K. Atomic Energy Authority.

When magnesium is used in the process described in B.P. 792,951, for the reduction of uranium dioxide, the metal produced tends to be pyrophoric. This can be avoided by including, in the mixture of uranium dioxide and magnesium, a proportion of alkaline earth metal chloride (which may also be magnesium chloride), afterwards leaching with dilute mineral, or acetic acid.

B.P. 792,953. Production of uranium metal. J. H. Buddery. To: U.K. Atomic Energy Authority.

A modification of B.P. 792,952, uranium dioxide and magnesium metal mixed with (preferably) magnesium chloride in certain proportions, is heated in a non-reactive vessel to 1200 deg. C. in an inert atmosphere. This temperature is maintained for at least one hour to promote growth of the uranium particles, then the reaction product is leached with dilute aqueous acid, the uranium particles are washed and vacuum freeze dried.

B.P. 792,972. Control of atomic power reactors. To: Atomic Energy of Canada, Ltd. (Canada).

Two types of control are necessary (1) fine control by neutron absorbing rods, by movement of reflector parts, or by variation of the level of the liquid moderator, and (2) high-speed control for emergency shut-down. Hitherto it was thought impossible to effect an emergency shut-down quickly enough by lowering the liquid level in the reactor vessel, but a method has been found to drain the moderator from the reactor core into a suitable storage space at such a rapid rate that shut-off rods are not required. This system is based on the use of gas (helium) pressure to keep the moderator level in the reactor vessel at its desired height. The moderator liquid flows rapidly by gravity into a storage chamber, when the gas pressure in this chamber is rapidly released.

B.P. 793,575. Production of polymers with ionizing radiation. To: Esso Research and Engg. Co. (U.S.A.).

Refers to a method of carrying out co-polymerization reactions, by exposing the reagents to radiation from a nuclear reactor or from fission products. A mixture of 60-100 parts of a conjugated diolefin, and up to 40 parts of a vinyl aromatic, is exposed to ionizing radiation (high velocity electrons or gamma rays) of 100,000 to 5,000 000 R/h long enough to form a polymer suitable for use as a drying oil. The irradiated material is passed to shielded storage tanks for its activity to decay, and is then fractionated and otherwise treated.